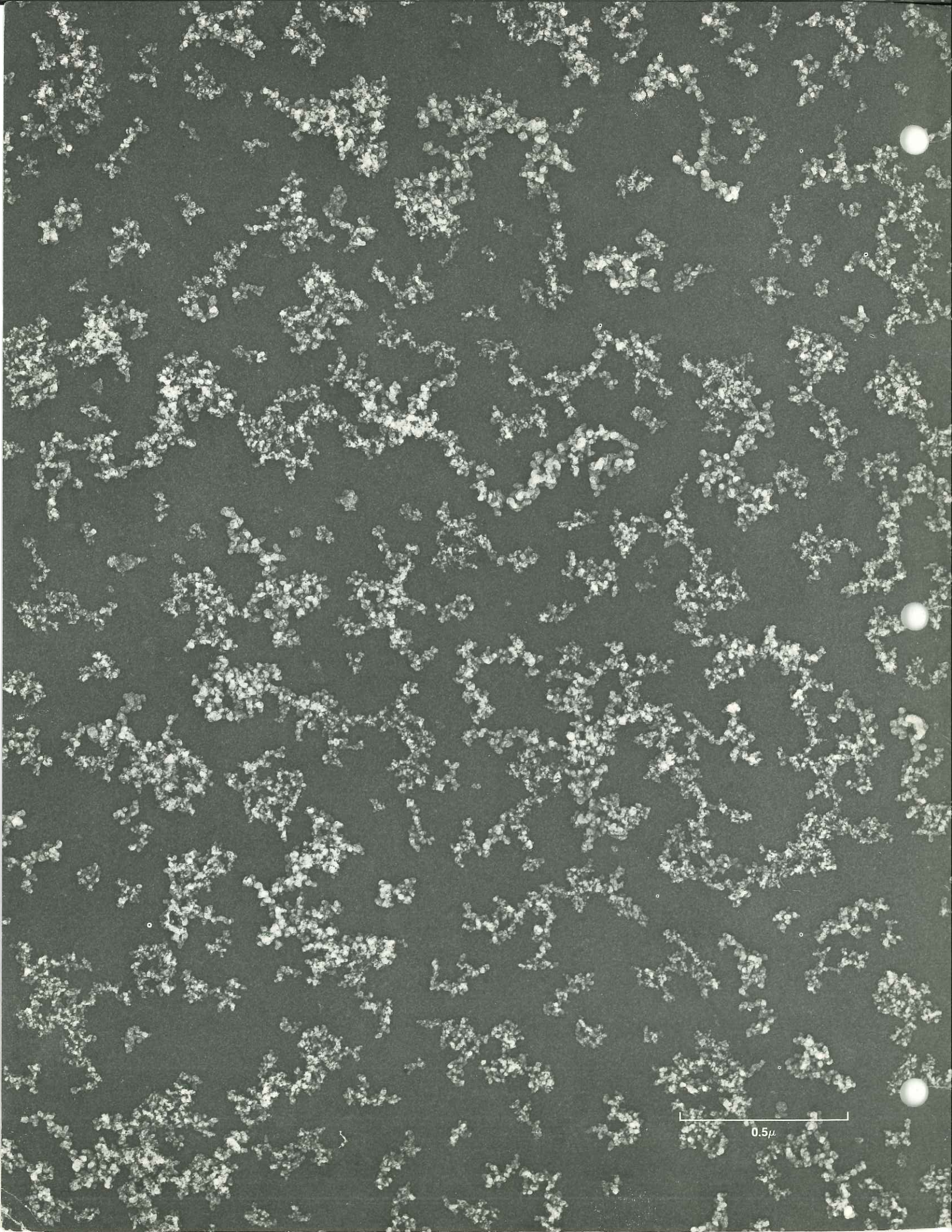
Cab-O-Sil® Properties and Functions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Left: Electron photomicrograph of Cab-O-Sil M-5 at a magnification of 80,000X (from a negative print). The chain-like aggregates consist of fused spherical primary particles of pure silica.

Cover: Model of the type of network which a sufficient concentration of Cab-O-Sil establishes when it is well dispersed in a liquid. The mechanism of this network formation, and the parameters which promote or hinder it, are described in this brochure.

Introduction

Cab-O-Sil is fumed silicon dioxide, a material which is generally regarded as unique in industry because of its unusual particle characteristics. Cab-O-Sil's extremely small particle size, its enormous surface area, its high purity and its chain-forming tendencies set it apart in a class of its own.

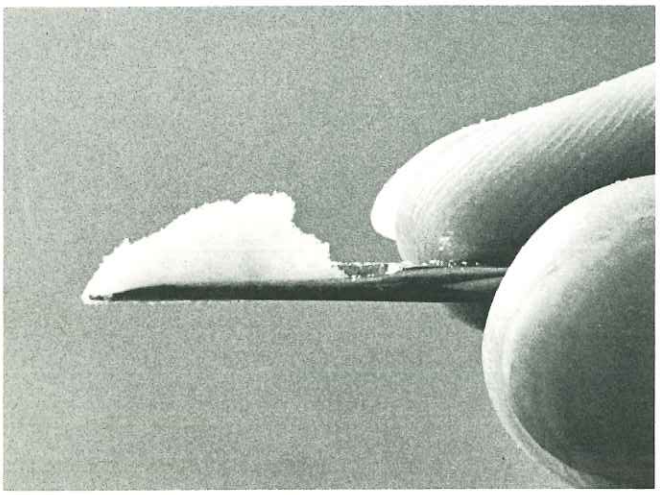
So useful has Cab-O-Sil become — in so wide a variety of products — that a Cab-O-Sil sample is a standard item on most laboratory shelves. Yet almost every day, someone finds a new way to use Cab-O-Sil.

Foremost among Cab-O-Sil's several contributions to product performance is its ability to modify a product's flow properties by building a three-dimensional network which alternately forms and disrupts in response to the degree of shear forces present — thereby controlling flow characteristics in accordance with the formulator's exact requirements.

At the same time the success of Cab-O-Sil in simultaneously enhancing several different properties of a formulated product makes possible distinctive chemical creations which would be difficult to achieve with any other single material — or even with the costly addition of several materials.

Combinations of thickening, thixotropy, suspension of solids, and optical clarity, for example, have been obtained in such diverse products as coatings, adhesives, cosmetics, inks, plastics, and rubbers. Cab-O-Sil's action to promote free flow of dry powders, granules and pellets has been beneficial in foods, cosmetics, and chemicals.

This general brochure is intended to (1) introduce the researcher to Cab-O-Sil and the properties it can impart to both liquid and dry systems, and (2) aid him in evaluating Cab-O-Sil in his own formulations. For certain industries and functions, special brochures have been prepared to aid in identifying the areas where Cab-O-Sil can help improve product and process effectiveness.



Light, fluffy, pure white Cab-O-Sil, piled on a laboratory micro-spatula.

Properties of Cab-O-Sil

Manufacture

Cab-O-Sil is produced by the hydrolysis of silicon tetrachloride vapor in a flame of hydrogen and oxygen, as shown in the reactions:

$$(1): 2H_2 + O_2 \longrightarrow 2H_2O$$

$$(2): SiCl_4 + 2H_2O \longrightarrow SiO_2\downarrow + 4HCl\uparrow$$

(Overall reaction):

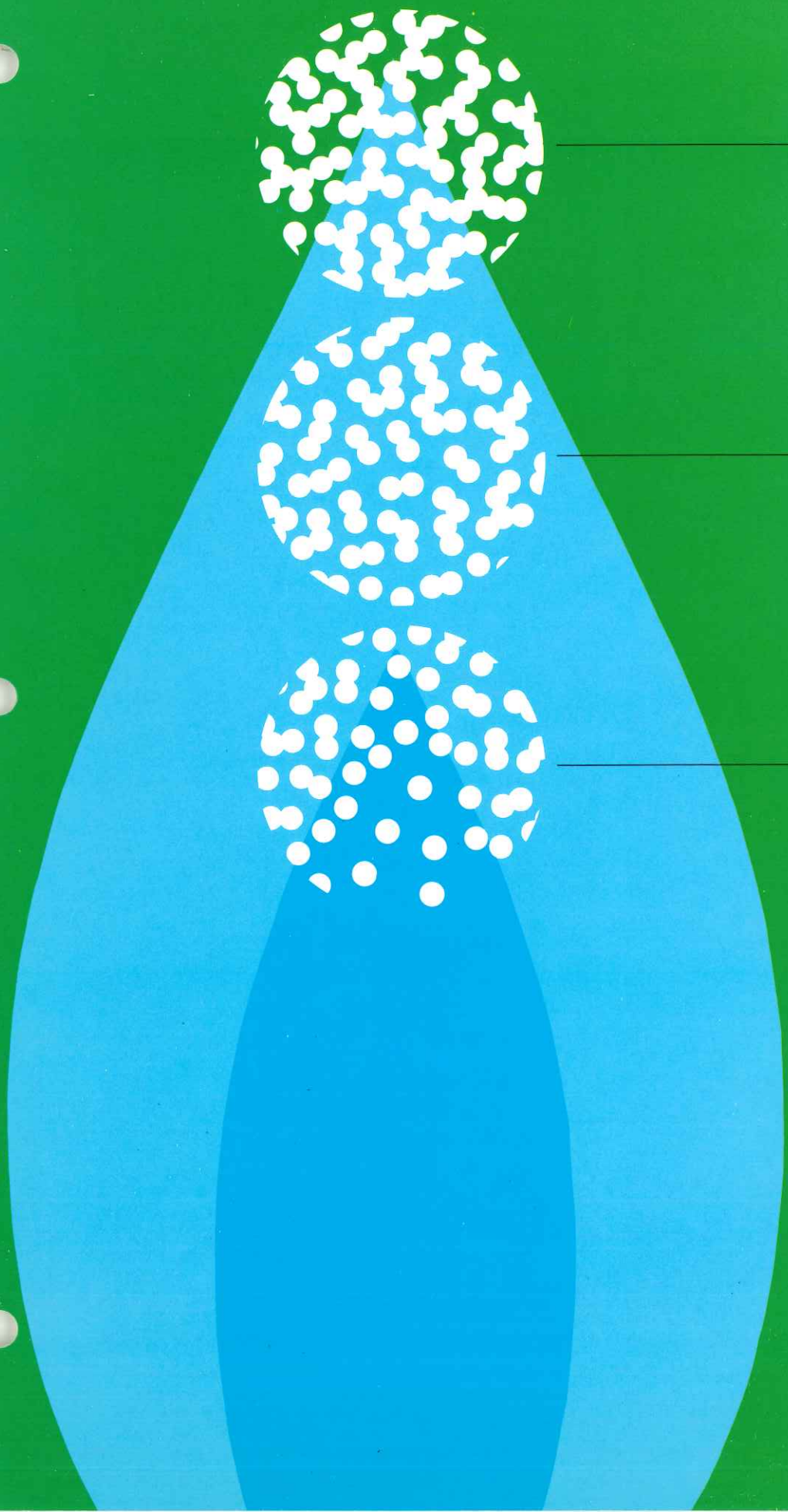
$$SiCl_4 + 2H_2 + O_2 \xrightarrow{1800^\circ C.} SiO_2\downarrow + 4HCl\uparrow$$

In the combustion process, as shown in Figure 1, molten spheres of silica are formed. The diameters of the silica spheres are varied through process parameters from averages of 7 to 14 millimicrons. This produces grades with final surface areas ranging from 400 square meters per gram through 200 square meters per gram, respectively.[1] These molten spheres, termed primary particles, collide and fuse with one another to form branched, three-dimensional, chain-like aggregates.

As the aggregates cool below the fusion temperature of silica (approximately 1710°C.) further collisions result in some reversible mechanical entanglement or agglomeration. Further agglomeration also takes place in the collection process.

The residual adsorbed hydrogen chloride on the Cab-O-Sil surface is then reduced to less than 200 ppm by calcination. Certain Cab-O-Sil grades go through an additional proprietary densing process which raises the bulk density from its normal average value of 2 pounds per cubic foot to more than 4 pounds per cubic foot, depending on the grade.

[1] *Surface areas are measured by the nitrogen adsorption method of S. Brunauer, P. H. Emmet, and E. Teller,* J. Am. Chem. Soc., 60, *309 (1938), and primary particle diameters are calculated from these, assuming spherical particles.*



3
During further cooling, collecting and bagging, the aggregates become physically entangled to form agglomerates. This process can be reversed by proper dispersion in a suitable medium.

2
While still semi-molten, the primary particles fuse irreversibly into secondary groupings called aggregates.

1
Silicon tetrachloride burns in a flame of hydrogen and oxygen to produce primary spherical particles.

Fig. 1. Schematic diagram of the flame process manufacture of Cab-O-Sil.

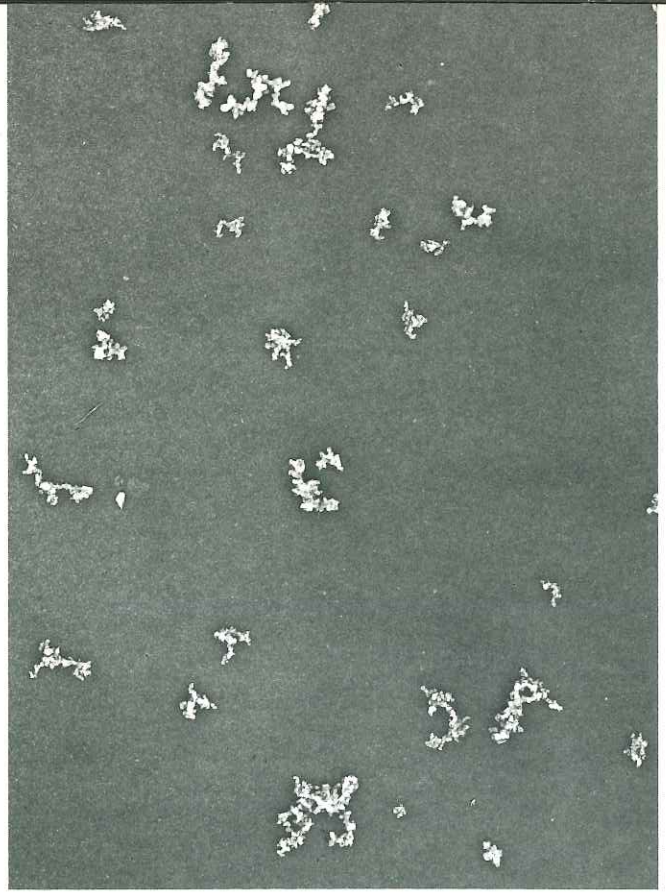


Fig. 2. Electron micrograph of Cab-O-Sil which has been highly dispersed in collodion to isolate the individual aggregates. Original magnification 7,938 X; final magnification 25,000 X (from a negative print).

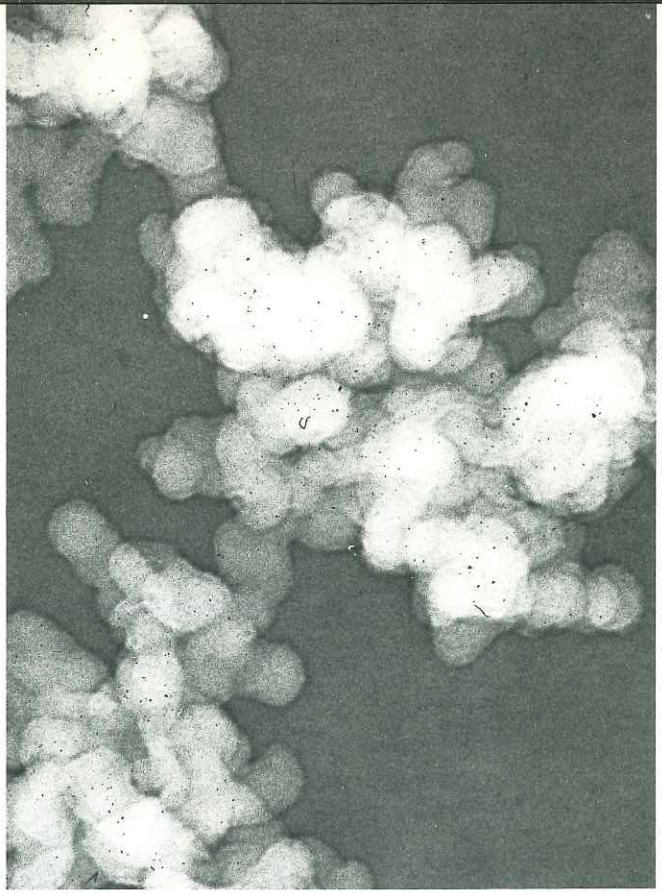


Fig. 3. Electron micrograph of a Cab-O-Sil aggregate showing the outlines of individual primary particles. Original magnification 62,300 X; final magnification 350,000 X (from a negative print).

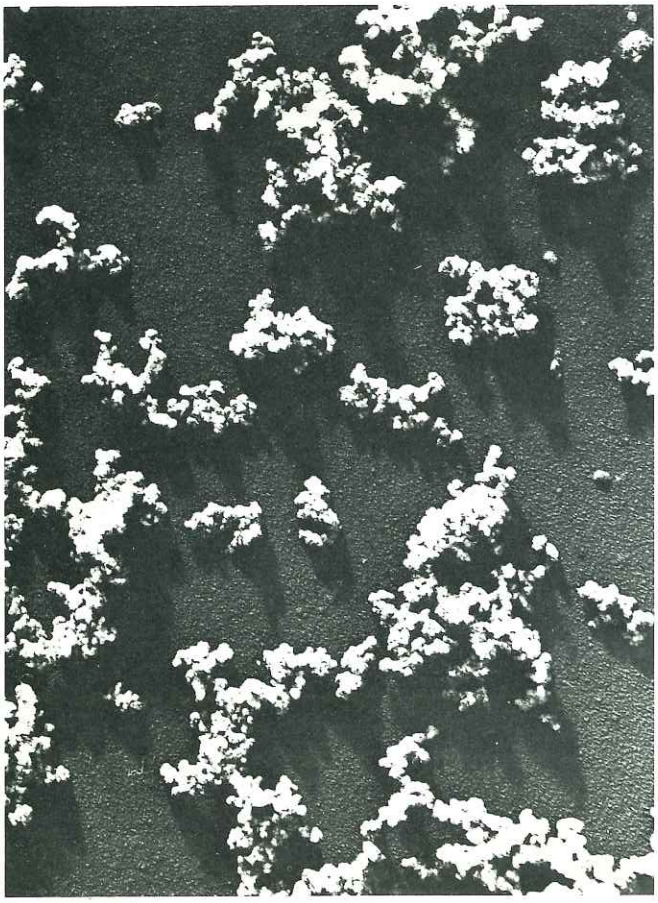


Fig. 4. Electron micrograph of Cab-O-Sil which has been shadowed with vaporized gold to highlight the three-dimensional random branching of the aggregates. Final magnification 50,000 X.

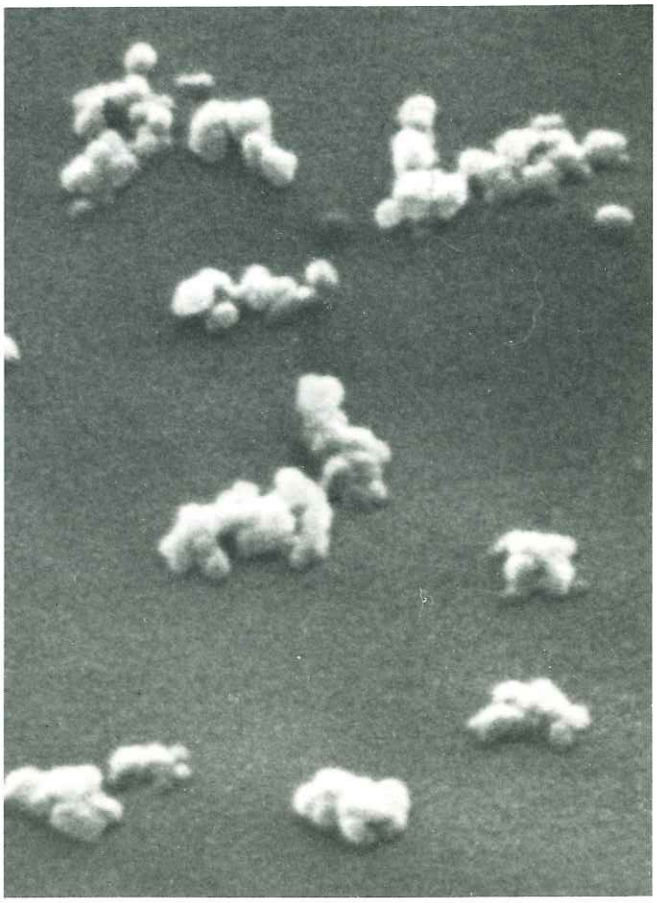
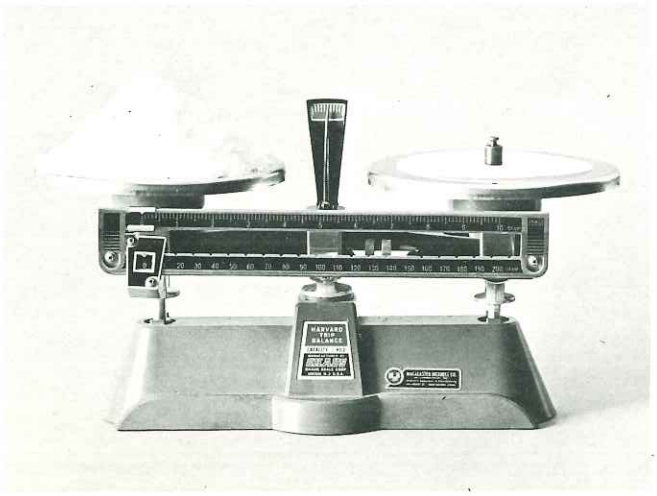


Fig. 5. Scanning electron micrograph of gold-coated Cab-O-Sil showing the sphericity of the individual particles in the aggregates. Final magnification 50,000 X.

Appearance

Cab-O-Sil is referred to as a fumed silica because of its smoke-like appearance as it forms in the flame. The term "pyrogenic" silica, formerly used, has been discontinued because of the ambiguity resulting from other common definitions of the word pyrogenic, i.e., "flammable" and "fever-producing." Cab-O-Sil has neither of these properties.

The fine, particulate nature of Cab-O-Sil can be seen in high magnification electron micrographs of the material. Fig. 2 is a typical electron micrograph of Cab-O-Sil, well dispersed in collodion to show the branched chain aggregates. There is virtually no mechanical entanglement (agglomeration) of the Cab-O-Sil aggregates in this micrograph. Fig. 3 is a much greater magnification of a single aggregate. It shows that the aggregate chain is in fact composed of many primary particles which have fused together. The maximum lengths of the aggregates are a few tenths of a micron. The electron micrographs of gold-shadowed Cab-O-Sil samples (Figs. 4 and 5) give an impression of the three-dimensional branching of the aggregates. They also show the extremely loose packing of the uncompressed aggregates.



Because of its low bulk density, Cab-O-Sil must be piled to overflowing on the pan to balance a ten gram weight.

Purity

The purity of the starting materials, the completeness of the flame process, and careful handling of the product result in a very high degree of chemical purity for Cab-O-Sil. Typical analytical values obtained from emission and atomic absorption spectra are shown in Fig. 6. The lack of significant amounts of ionic impurities gives Cab-O-Sil excellent dielectric properties, so it is used frequently in reinforcement applications in polymeric systems for electrical insulation — including organic rubbers, vinyl polymers and silicones.

Typical Values Obtained by Emission Spectrographic Analysis[1]

Element	ppm[2]	Element	ppm
Al	8	Mn	< 2
B	<10	Mo	< 2
Ba	<30	Nb	< 10
Be	< 2	P	<300
Bi	< 2	Sn	< 3
Ca	<10	Ti	< 2
Co	<20	V	< 2
Cr	< 2	Zn	< 30
Fe	< 2	Zr	< 5
Mg	< 2		
Fluorides	<10 (Total fluorides as determined by various methods)		

Typical Values Obtained by Atomic Absorption Spectrographic Analysis[1]

Element	ppm[2]	Element	ppm
As	<0.2	Ni	<0.4
Cd	<1.0	Pb	<0.1
Cu	<0.5	Sb	<1.0
Hg	<0.01	Se	<1.0
Na	20-40		

The "less than" sign (<) indicates that the element was not detected at this level, the limit of resolution of the instrument. If present, the level of the element was no higher than the amount shown and probably lower.

[1] *These data in no way constitute a specification or certification for any particular shipment or shipments, but simply represent typical values based on analysis of spot samples from actual production of Cab-O-Sil.*
[2] *ppm = parts per million.*

Fig. 6. Analysis of a typical Cab-O-Sil, Grade M-5, by emission spectrographic analysis and atomic absorption.

Density

The true density of the aggregate is 2.20 grams per milliliter, but the bulk density of uncompressed Cab-O-Sil is much lower, being approximately 0.032 grams per milliliter (2 pounds per cubic foot). In the compressed grades this is increased to 4 to 6 pounds per cubic foot.

Compaction of the Cab-O-Sil results in the formation of large agglomerates, formed through mechanical entanglement of the aggregates. In order to obtain optimum utilization of Cab-O-Sil in its various applications, these agglomerates must be untangled into individual aggregates through the use of suitable dispersion equipment.

Gas adsorption studies of Cab-O-Sil have shown that the material is non-porous. Thus adsorption and desorption processes are rapid since molecules are only held physically on exterior surfaces, not entrapped in pores. However, the clustered nature of the aggregates may make it difficult for large molecules — of polymers for example — to gain access to all surfaces which can be reached by the gas molecules used in the surface area measuring procedure.

Structure

The amorphous nature of Cab-O-Sil is shown by the absence of lines in its X-ray diffraction pattern. For comparison, this pattern is shown with the patterns of some well-known crystalline forms of silica, i.e., α-quartz, β-cristobalite and β-tridymite, in Fig. 7. The amorphous form is probably caused by the extremely rapid cooling of the silica aggregates, which takes place in only a few thousandths of a second.

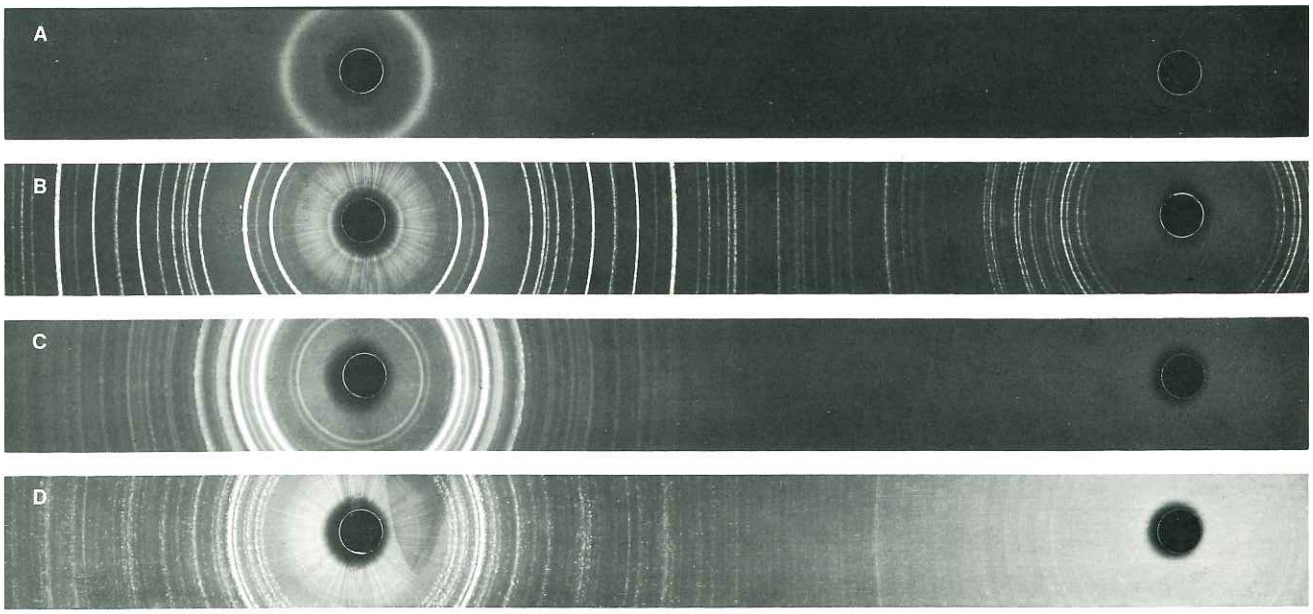
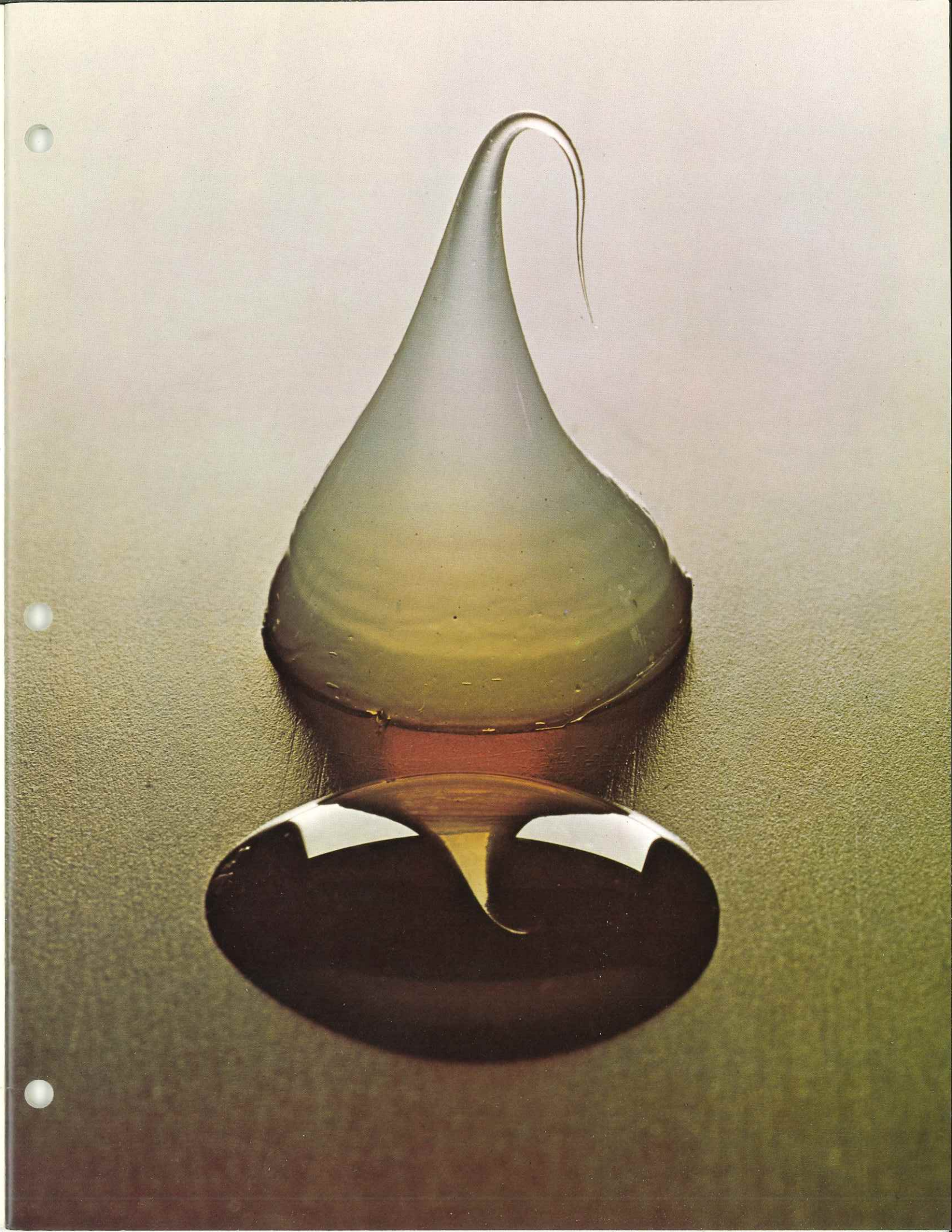


Fig. 7. Comparison of the X-ray diffraction pattern of amorphous Cab-O-Sil (A) with those of the common crystalline silicas: α-quartz (B) β-cristobalite (C) and β-tridymite (D).

Facing page: Thickening. The proper concentration of Cab-O-Sil can produce any degree of controlled viscosity — from slightly thickened to firm gel.



Refractive index

The refractive index of Cab-O-Sil is 1.46 — very close to that of many organic solvents and other materials. Glycerine, butyl alcohol, certain hydrocarbons, oils and many other liquids can be thickened without loss of transparency. Similarly, silicone rubbers and other transparent polymers can be reinforced with Cab-O-Sil with little loss of clarity.

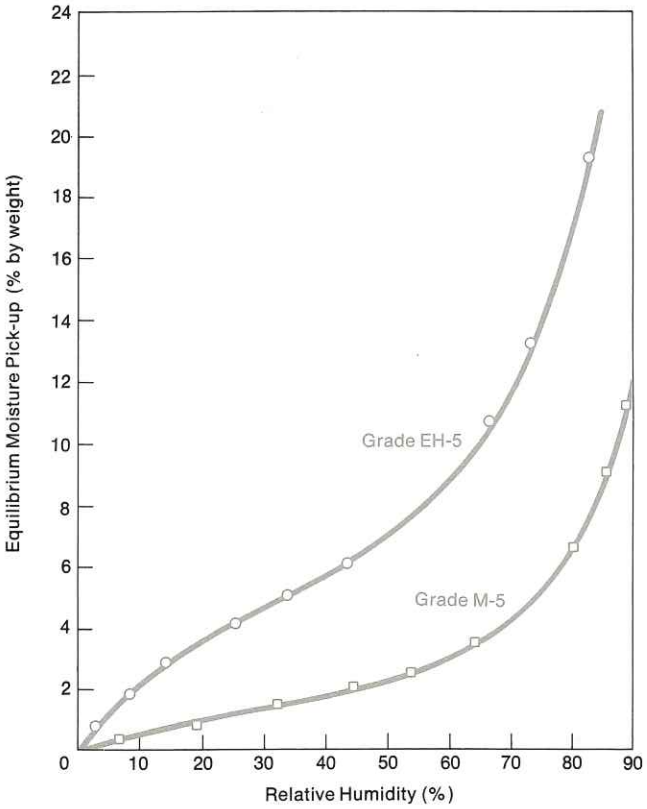


Fig. 8. Moisture adsorption by Cab-O-Sil as a function of the relative humidity at 23.5°C.

Surface chemistry

The surface chemistry of Cab-O-Sil is extremely important, especially in relation to its ability to thicken non-polar and semi-polar liquid systems. During the formation of Cab-O-Sil, hydroxyl groups become attached to some of the silicon atoms on the particle surface. This makes the Cab-O-Sil surface hydrophilic and capable of hydrogen bonding with suitable molecules of materials in vapor, liquid or solid form.

Typical equilibrium moisture adsorption isotherms (room temperature) are shown in Fig. 8. The moisture adsorption capacities of the various Cab-O-Sil grades increase with increases in their surface areas. The ability of Cab-O-Sil to adsorb moisture is one of the properties which makes it an excellent free-flow agent for lumpy or hygroscopic solids. The moisture content of Cab-O-Sil in bags ranges from approximately 1% for Grade M-5 to 3% for Grade EH-5, at the time of bagging at the point of manufacture. Since the material of which the bag is made is porous, the moisture content of Cab-O-Sil can vary unless the bag is protected from ambient atmospheric conditions. Such protection is provided when needed by enclosing the bag in a sealed polyethylene overslip.

The moisture adsorbed on the surface of Cab-O-Sil can be removed by evacuation at room temperature (in a vacuum equal to 10^{-2} millimeters of mercury) or by heating at 110°C.

Analysis of the water vapor adsorption isotherms indicates that only a part of the Cab-O-Sil surface is hydrophilic. Chemical and thermogravimetric analyses indicate that there are an average of approximately 3.5 to 4.5 hydroxyl groups per square millimicron of silica surface. It has been calculated that if each of the surface silicon atoms had one hydroxyl group attached, there would be a maximum of 7.85 hydroxyl groups per square millimicron.

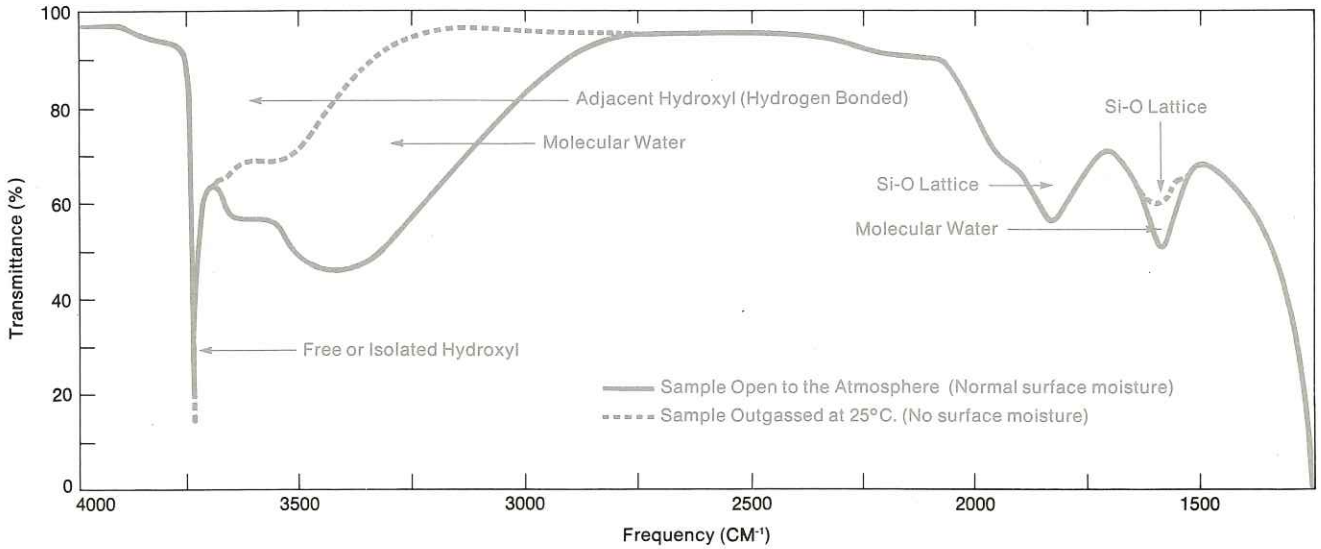


Fig. 9. Infrared spectra of Cab-O-Sil, with and without normal adsorbed surface moisture.

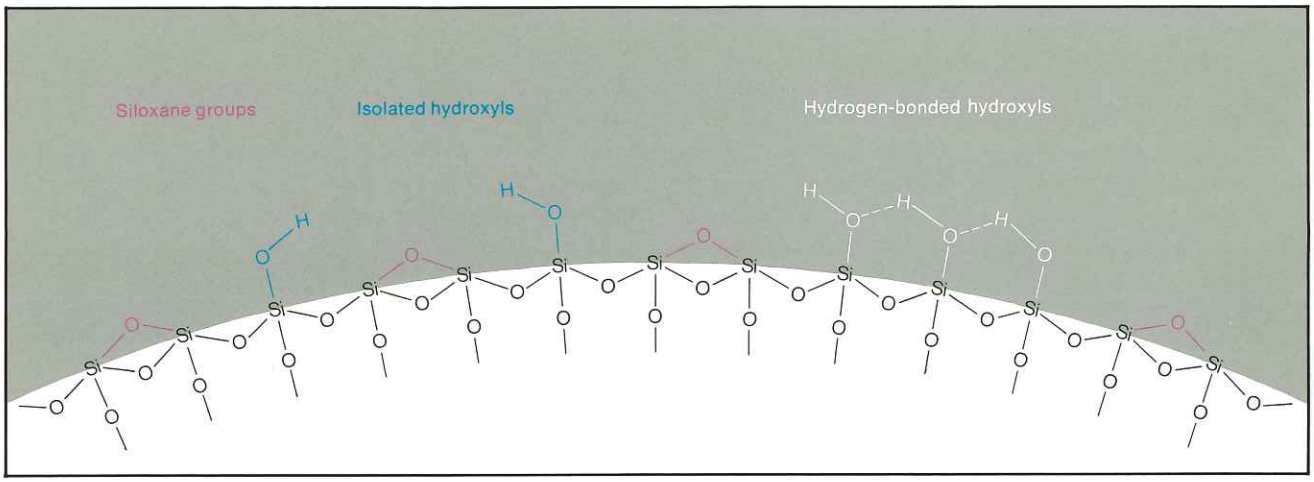


Fig. 10. Typical groups which can occur on the Cab-O-Sil aggregate, determining its surface chemistry.

The infrared spectrum of Cab-O-Sil is interpreted as indicating that there are at least two different types of hydroxyl groups on the surface. This spectrum is shown in Fig. 9.

The chemical groups occurring on the surface of Cab-O-Sil are shown in Fig. 10. The three groups which can be identified are: 1) the isolated hydroxyl group, 2) hydrogen-bonded hydroxyl groups, and 3) the siloxane group.

The isolated hydroxyl group attached to a surface silicon atom, surrounded by siloxane groups (Si-O-Si), and characterized by the infrared absorbance peak at 3750 cm^{-1}, is hydrophilic. Hydrogen-bonded hydroxyl groups, resulting from the presence of hydroxyl groups attached to neighboring surface silicon atoms, are characterized by the broad peak at 3700 to 3500 cm^{-1}. They are also hydrophilic. The siloxane group is non-polar and accounts for the hydrophobic characteristics of that part of the silica surface.

When heated above 110°C., the Cab-O-Sil surface undergoes reversible dehydration as shown in Fig. 11. The release of water forms additional siloxane groups. The temperature-dependence of the dehydration process is shown in the thermogravimetric analysis plot (Fig. 12). At temperatures above 800°C. the Cab-O-Sil starts to sinter, with a consequent loss in surface area. Surface hydroxyls removed by dehydration can be restored by exposure to air at 100% relative humidity or by immersion in water, depending on the temperature and degree of dehydration. The sintering process, however, is irreversible and Cab-O-Sil, once it has been subjected to sintering, cannot be restored to its former condition.

The presence of hydroxyl groups on the surface of the Cab-O-Sil aggregate is the key to the mechanism through which Cab-O-Sil is able to perform many of its functions. This is discussed in the section titled *Mechanisms of Cab-O-Sil,* page 12.

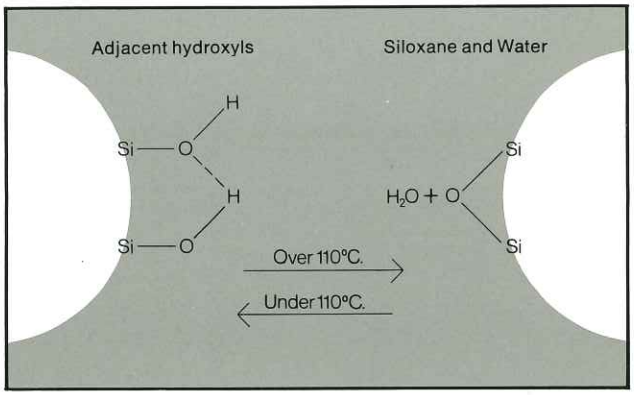


Fig. 11. Reversible dehydration of the Cab-O-Sil surface.

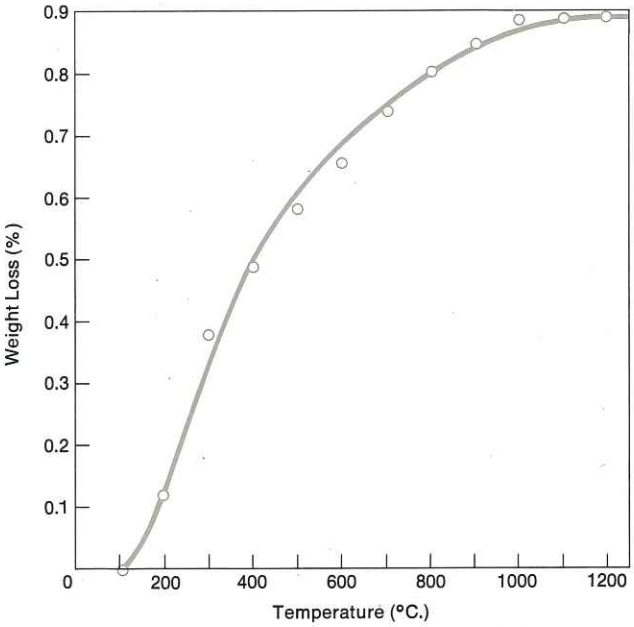


Fig. 12. Thermogravimetric analysis of Cab-O-Sil. Above 110°C. the weight loss is caused by a gradual loss of water as the surface hydroxyls undergo condensation, as shown in Fig. 11.

Health and safety data

Toxicology The sub-micron size and the amorphous nature of Cab-O-Sil combine to make it a relatively safe, non-hazardous material. Manufacturing experience and tests with laboratory animals have given the following results:

1. There have been no known cases of silicosis caused by inhalation of Cab-O-Sil. Silicosis is normally associated with breathing microscopic particles of crystalline silica. Cab-O-Sil is sub-microscopic in size and amorphous. Thus there are no sharp edges to cause damage to lung tissue.

2. Direct application of Cab-O-Sil to the eyes of albino rabbits produced only a mild irritation which subsided completely within 48 hours.

3. Fifteen applications of Cab-O-Sil to the intact and intentionally abraded skin of albino rabbits produced only mild dermal irritation. No systemic toxicity, gross pathology or microscopic pathology were observed that could be attributed to the Cab-O-Sil. No difference in silica content of blood, urine, spleen, liver and kidneys was observed between the control and test animals.

4. Exposure of albino rats for one hour to an atmosphere containing 200 milligrams of Cab-O-Sil per liter produced no mortalities during the test, immediately after the test or during the fourteen day period following the test.

5. A single oral dose of Cab-O-Sil to albino rats showed no gross signs of systemic toxicity. No mortalities occurred at dosage levels as high as 3.16 grams per kilogram of body weight.

6. Male and female albino rats were fed Cab-O-Sil in their diets at levels up to 5.0% for a period of 90 days. No significant differences between the test animals and the control animals were observed. These observations included growth rates, food consumption, survival, gross and microscopic pathology and silicon dioxide content of liver, spleen, kidneys, blood and urine.

Regulatory status The use of Cab-O-Sil (99.80% SiO_2) has been approved by the Food and Drug Administration for many food applications as both a direct food additive and as a substance allowed in the manufacture of materials that come into direct contact with food in various producing, manufacturing, packing, processing, preparing, transporting and holding operations. Pertinent sections in Title 21 CFR are cited below:

172.480	(Principal Section) Anti-Caking and Free Flow in Foods
133.136 (b)	Anti-Caking in Grated Cheese
160.105 (a) (d)	Anti-Caking in Dried Eggs
160.185 (a)	Anti-Caking in Dried Egg Yolks
172.230 (a)	Microencapsulation
173.340 (a)	Defoaming Agents
175.300 (a)	Pigment in Coatings
175.390	Food Contact Coatings
176.200 (d)	Defoaming Agent in Coatings
176.210 (d)	Defoaming Agent
177.1200 (b)	Cellophane Component
177.2420 (b)	Food Contact Articles
177.2600 (a)	Filler in Rubber
182.90	Anti-Foaming, Food Packaging Migration
573.940	Animal Feeds and Water

Title 40 CFR:

180.1001 (c) (d) Exemption from Tolerance

Food Chemical Codex Silicon Dioxide (Cab-O-Sil) meets the acceptance standards of the Codex.

Cosmetic use Cab-O-Sil has been authorized by FDA for use in amounts of up to 3% by weight in cosmetic applications.

Pharmaceutical use Cab-O-Sil has been authorized by FDA for use of up to 3% by weight in internal applications and up to 8% by weight in pharmaceutical products for use in topical applications.

National Formulary Cab-O-Sil meets the requirements for purity and testing for Colloidal Silica as prescribed in N.F. XIV.

EPA status Registered in the EPA Inventory as Silicon Dioxide, C.A.S. #7631-86-9; EPA Code A-343-7356.

Hazardous Materials Act (P.L. 93-633) Cab-O-Sil is classified as a non-hazardous, non-restricted substance under the provisions of the Act of 1977.

Federal Labelling Act Cab-O-Sil meets all of the requirements of this Act with respect to exemptions from Hazardous labelling.

Handling Since Cab-O-Sil is a dry powder material subject to dusting and other behavior characteristics of dry powder materials, we recommend the following for maximum comfort and safety:

1. Avoid continued excessive inhalation.
2. Use an approved, well-fitting dust mask and adequate ventilation of the work area.
3. Wear eye protection.
4. Since any dry powder material can build static electrical charges when subjected to the friction of mixing, sliding or conveying, provide proper precautions, such as adequate electrical grounding of equipment and/or inerting the air space above flammable or explosive liquids, to prevent accidents. Refer to National Fire Protection Association booklet: NFPA #77-1972 "Recommended Practice on Static Electricity" for further information.

Compliance with the various regulations of OSHA, EPA and other federal agencies, as well as those of state and local governments, is incumbent upon the user. Cabot Corporation will supply data on request, but cannot guarantee compliance, since the conditions of use are beyond our control.

Grades of Cab-O-Sil

Through variations in the manufacturing process, grades of Cab-O-Sil are produced with differing particle sizes, surface areas and bulk densities. These modifications do not affect the silica content, specific gravity, refractive index, color or amorphous form.

The grades of Cab-O-Sil and their quality control specifications and properties are shown in the accompanying tables, Figs. 13 and 14.

Grade[1]	Surface Area[2] (m^2/gm)					Density (lbs/ft^3)		pH (4% in H_2O)		
	200 ±25	255 ±15	325 ±25	390 ±40	400 ±20	2.3 max.	4.5 ±0.5	3.6-4.3	3.6-4.3	3.6-4.3
M-5	●					●		●		
MS-7	●						●		●	
MS-75		●					●		●	
HS-5			●			●			●	
EH-5				●		●		●		
S-17					●		●			●

All grades: Residue on 325 Mesh = 0.02% max.

Values and ranges are those obtained on freshly-manufactured representative samples.

[1] *Not a specification. See footnote, Fig. 6.*
[2] *BET Method. See section on Properties.*

Fig. 13. Tested quality control standards by grade.

Grade	Nominal Particle Size (Diameter in Microns)[1]				Ignition Loss (1000°C. moisture-free basis)			
	0.014	0.011	0.008	0.007	1.0%	1.5%	2.0%	2.5%
M-5	●				●			
MS-7	●				●			
MS-75		●				●		
HS-5			●				●	
EH-5				●				●
S-17				●				●

All grades: Bulking Value = 5.5 gal./100 lbs.
Specific Gravity = 2.2
Color = White
Silica Content (Ignited Sample) = >99.8%
Refractive Index = 1.46
X-ray Form = Amorphous

These figures represent average values obtained, but are not to be construed as rigid quality control standards. See footnote 1, Fig. 6.

[1] *Calculated from the surface areas (BET Method) assuming sphericity of particles.*

Fig. 14. Typical properties by grade

Mechanisms of Cab-O-Sil

Facing page: Emulsification. Dispersed Cab-O-Sil stabilizes emulsions of immiscible liquids, as on right — prevents phase separation, as on left.

In liquid systems

It has been explained previously that some of the surface silicon atoms of Cab-O-Sil bear surface hydroxyl groups (See *Surface Chemistry,* page 8). These surface hydroxyls are then capable of forming hydrogen bonds between Cab-O-Sil aggregates. A network of silica will form when a sufficient concentration of Cab-O-Sil is thoroughly dispersed in most liquid systems. This is the arrangement shown in Fig. 15.

The exceptional ability of Cab-O-Sil to provide thickening, thixotropy, suspension and related properties in liquid systems depends largely on this tendency of its aggregates to link together into chains through hydrogen bonding.

In non-hydrogen-bonding systems, the concentration of Cab-O-Sil is the most important determinant of the degree of chain formation. It is in these systems that Cab-O-Sil displays its greatest efficiency as a thickener and thixotropic agent.

However, dispersion is an important factor, and in unusual cases where dispersion has been carried much too far, a reduction in final viscosity will result. Physically, this means that the Cab-O-Sil network has been broken into extremely small pieces and widely scattered (Fig. 17, page 14). The fragments have become so widely spaced from each other that it is statistically unlikely that they will be able to reunite sufficiently to form the continuous filaments necessary for network formation. See the section on *Degree of Dispersion,* page 19.

In the presence of water or other hydrogen-bonding liquids — alcohols, carbonyl compounds, ethers, amines, mercaptans and others — hydrogen bonding will occur between the Cab-O-Sil hydroxyls and the solvent molecules (Fig. 16). This will result in partial or total solvation of the Cab-O-Sil aggregates, thus reducing chain formation or eliminating it entirely.

In systems of intermediate hydrogen-bond-forming tendency, the solvent-to-Cab-O-Sil and chain-forming reactions will take place competitively. The extent of chain formation depends on the ratio of Cab-O-Sil concentration to the number and location of hydrogen-bonding and non-hydrogen-bonding groups present on the other components of the system — and on the degree of dispersion.

When the system contains mono-functional hydrogen-bonding molecules in appreciable concentration, formation of chains of aggregates is virtually eliminated. The polar end of the molecule is preferentially adsorbed on the silica surface, preventing hydrogen bonding. This halts further chain formation at this particular site, in much the same way that a chain-terminating substance operates in a polymerization reaction. Even in these systems, careful selection of the proper chemical modifiers, as discussed in the section on *Additives,* can lead to efficient use of Cab-O-Sil.

The degree of network formation which Cab-O-Sil is able to produce in any system is dependent on a number of parameters. These are more fully described in the section *Thickening and Thixotropy,* page 17.

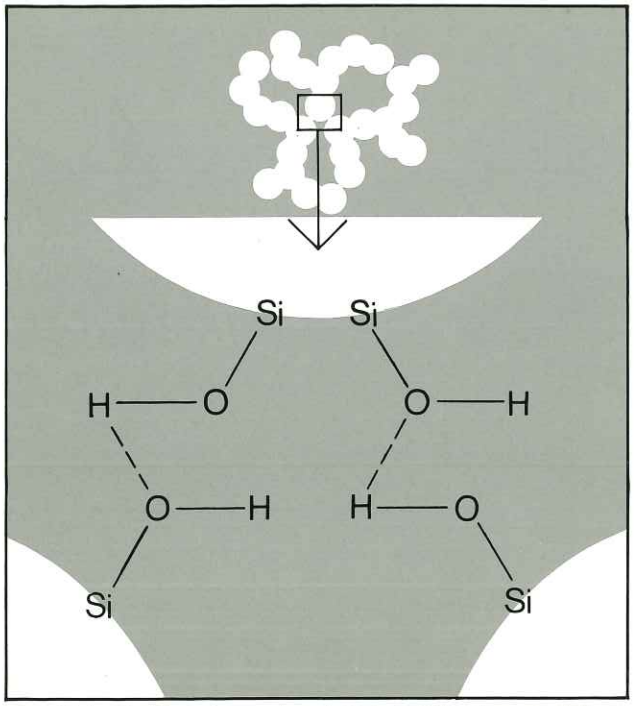


Fig. 15. In liquid systems at rest, Cab-O-Sil's characteristic network forms as the aggregates are drawn into contact by hydrogen bonding between the surface hydroxyl groups.

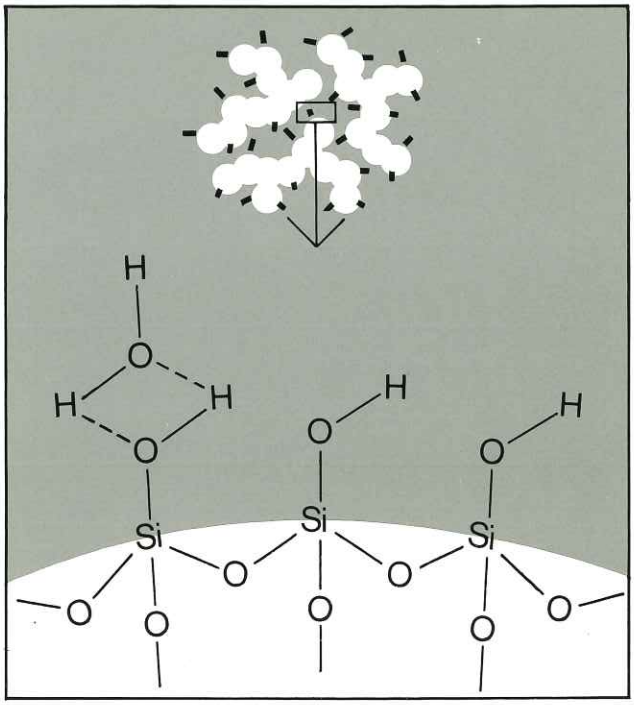
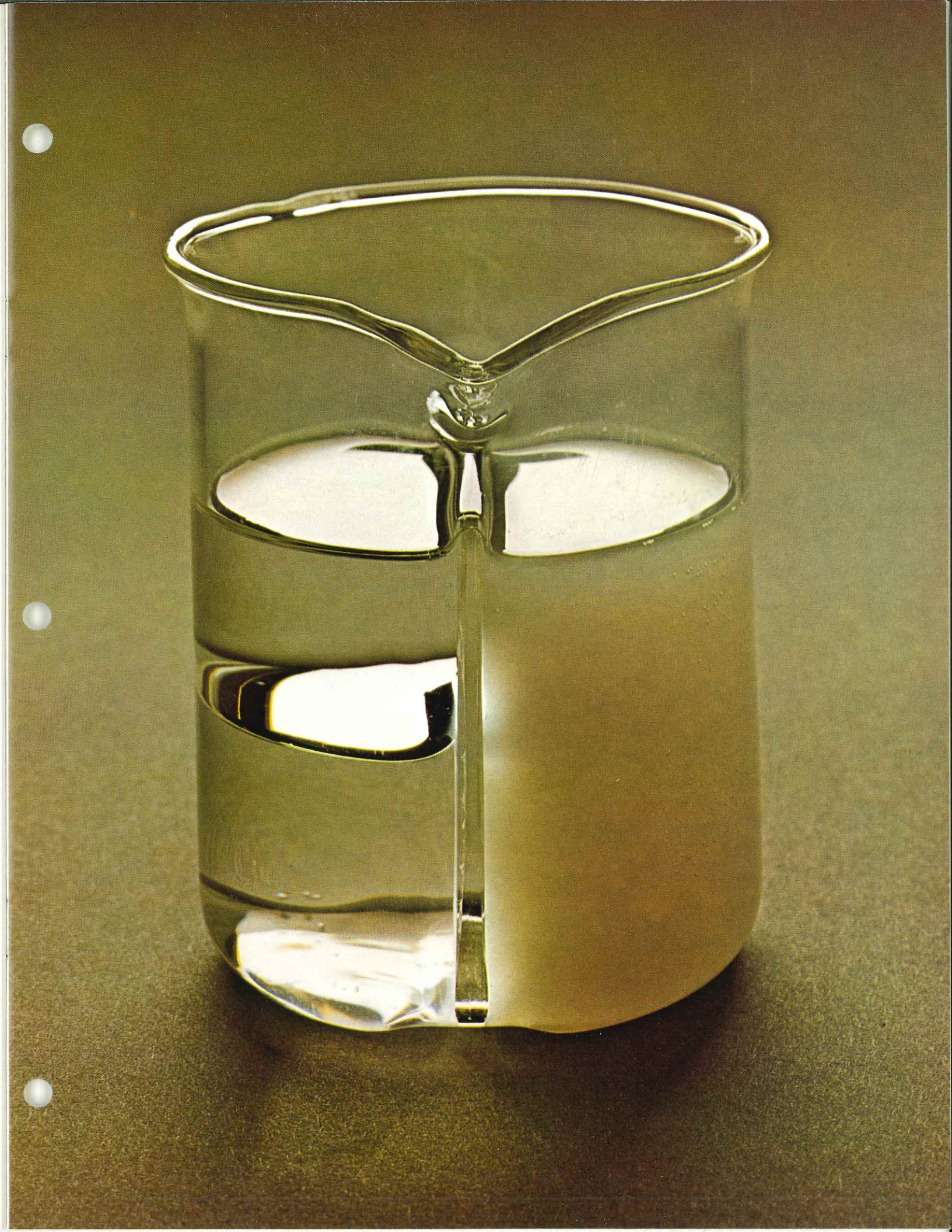


Fig. 16. Hydrogen bonding between Cab-O-Sil surface hydroxyls and molecules of other polar substances may partially inhibit or completely prevent chain formation.



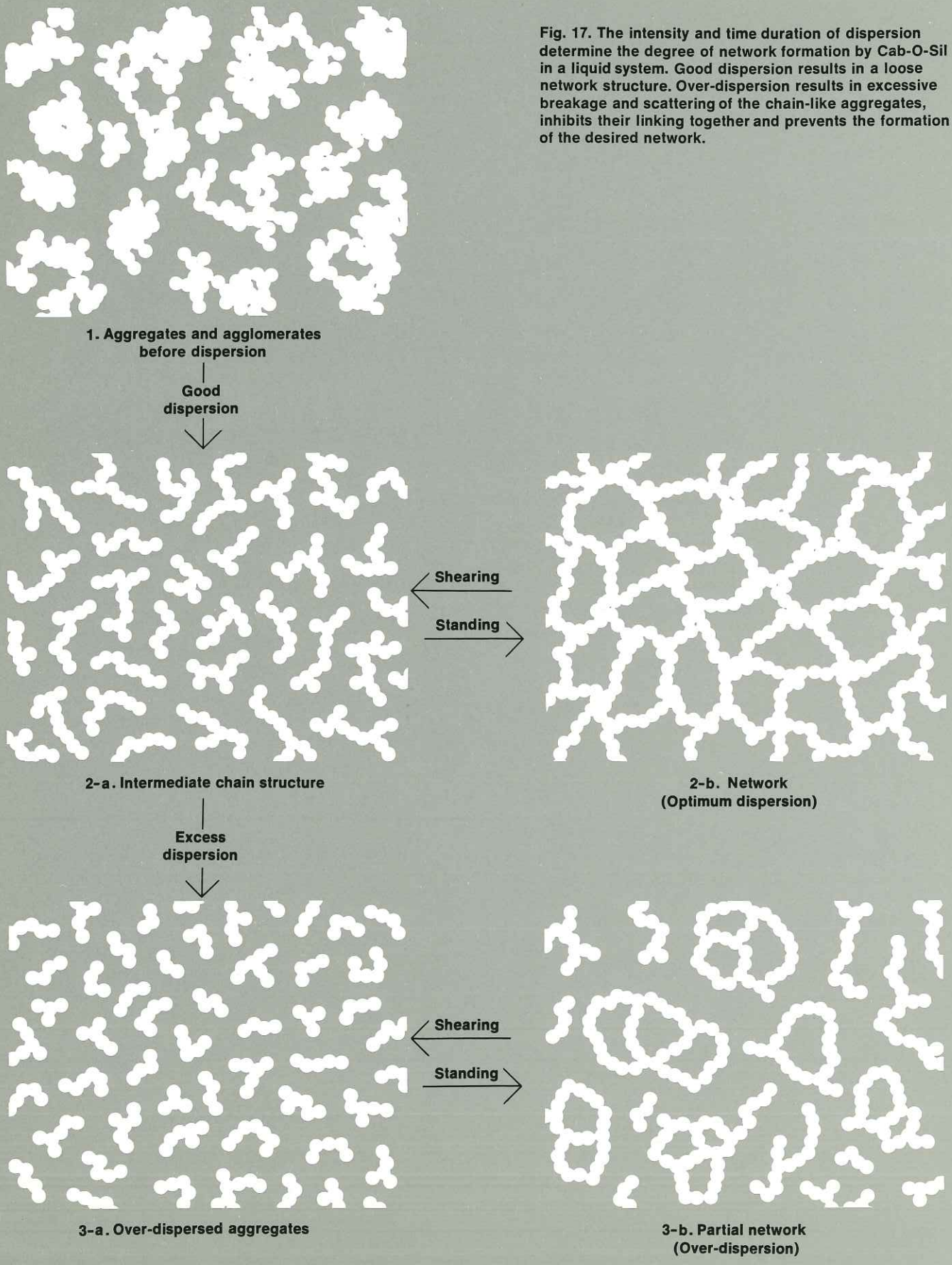


Fig. 17. The intensity and time duration of dispersion determine the degree of network formation by Cab-O-Sil in a liquid system. Good dispersion results in a loose network structure. Over-dispersion results in excessive breakage and scattering of the chain-like aggregates, inhibits their linking together and prevents the formation of the desired network.

In dry systems

Cab-O-Sil can perform through different mechanisms in dry materials. When added to particulate systems it 1) promotes free flow; whereas in stabilized films or coatings it provides 2) frictionizing, and/or 3) anti-blocking characteristics.

Free flow The free-flow, anti-caking and anti-clogging characteristics which are imparted to powders, granules and pellets by the addition of small amounts of Cab-O-Sil are the result of several actions. The submicroscopic size of the silica aggregates permits them to move easily between the larger particles of the other dry ingredients, and in most cases Cab-O-Sil probably forms a coating on the powder particles. Cab-O-Sil's tremendous surface area is the reason very small amounts can provide effective action.

After blending with the other powders, Cab-O-Sil adsorbs some or all of the moisture which may be present in or on the product particles. It then serves as a layer of tiny, mobile "ball bearings" which greatly facilitate slippage of the larger product particles across each other (Fig. 18). The Cab-O-Sil aggregates prevent other particles from contacting each other to form the nuclei that would otherwise lead to the formation of larger lumps and cakes. This spacing and lubricating action helps to keep materials moving through such apertures as process equipment valves, spray heads, storage bin openings, bag and drum spouts and aerosol nozzle orifices.

Frictionizing When Cab-O-Sil is incorporated in a coating material in which it is firmly embedded but partially exposed at the surface, the micro-roughness imparted to the coating surface by the Cab-O-Sil aggregates contributes non-slip and non-stick qualities (Fig. 19). The coefficient of friction of these coatings is effectively increased by the tiny surface irregularities imparted by Cab-O-Sil.

Anti-blocking Cab-O-Sil also benefits products coated with adhesives of the water-activated, solvent-activated and holt-melt types. After application of the adhesive, these materials are often stored for extended periods of time until they are finally activated and used. The irregularities imparted by Cab-O-Sil can prevent perfect and continuous contact between two surfaces, which can lead to adhesion and the phenomenon known as blocking — a problem frequently encountered by manufacturers of plastic sheet and film. Blocking may also occur when paper, paperboard, wood, plastic and other materials are coated with waxes, resins or adhesives, then stored in hot humid environments prior to activation by water, solvents or heat. When the coatings are activated, however, the Cab-O-Sil becomes immersed in the semi-liquid material and good adhesive properties result.

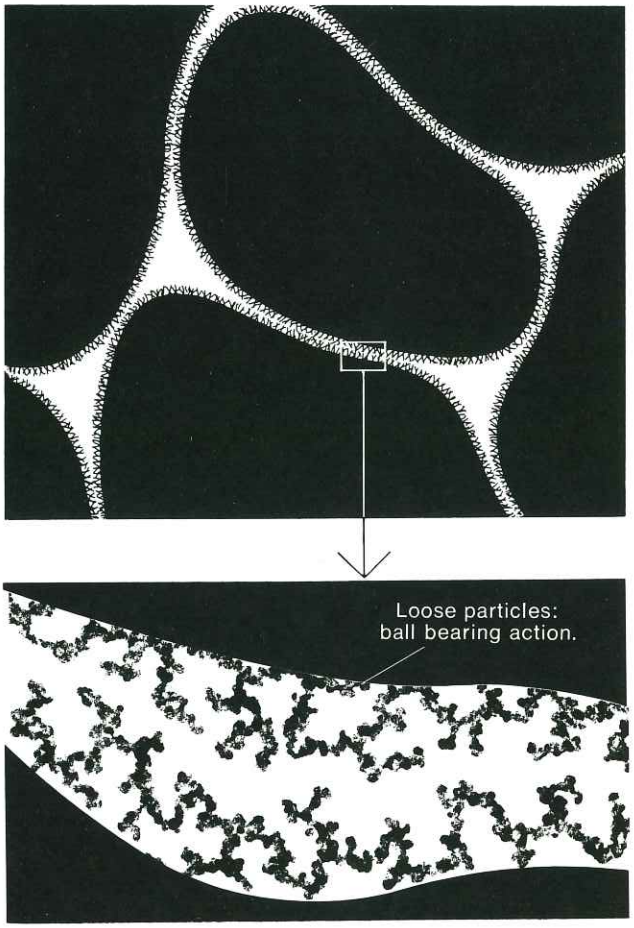


Fig. 18. Cab-O-Sil particles form a thin movable layer on the larger particles of powdered materials with which they are mixed. Acting as tiny spacers they produce a ball-bearing effect, sliding and tumbling to promote free flow of the powder.

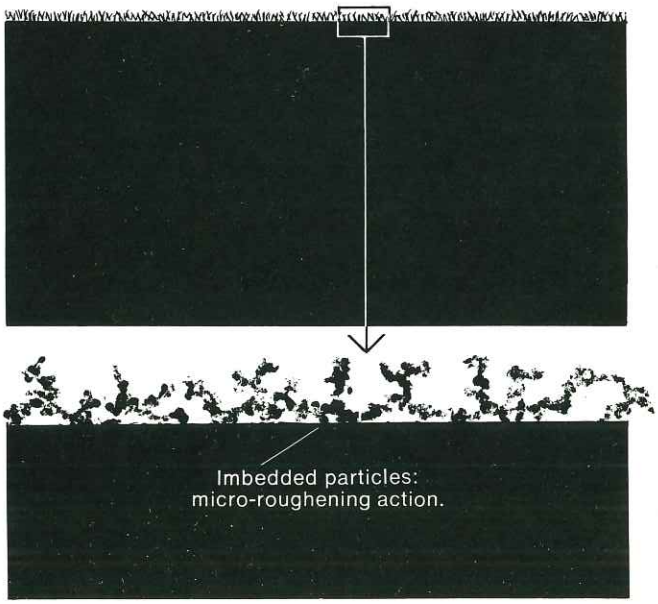
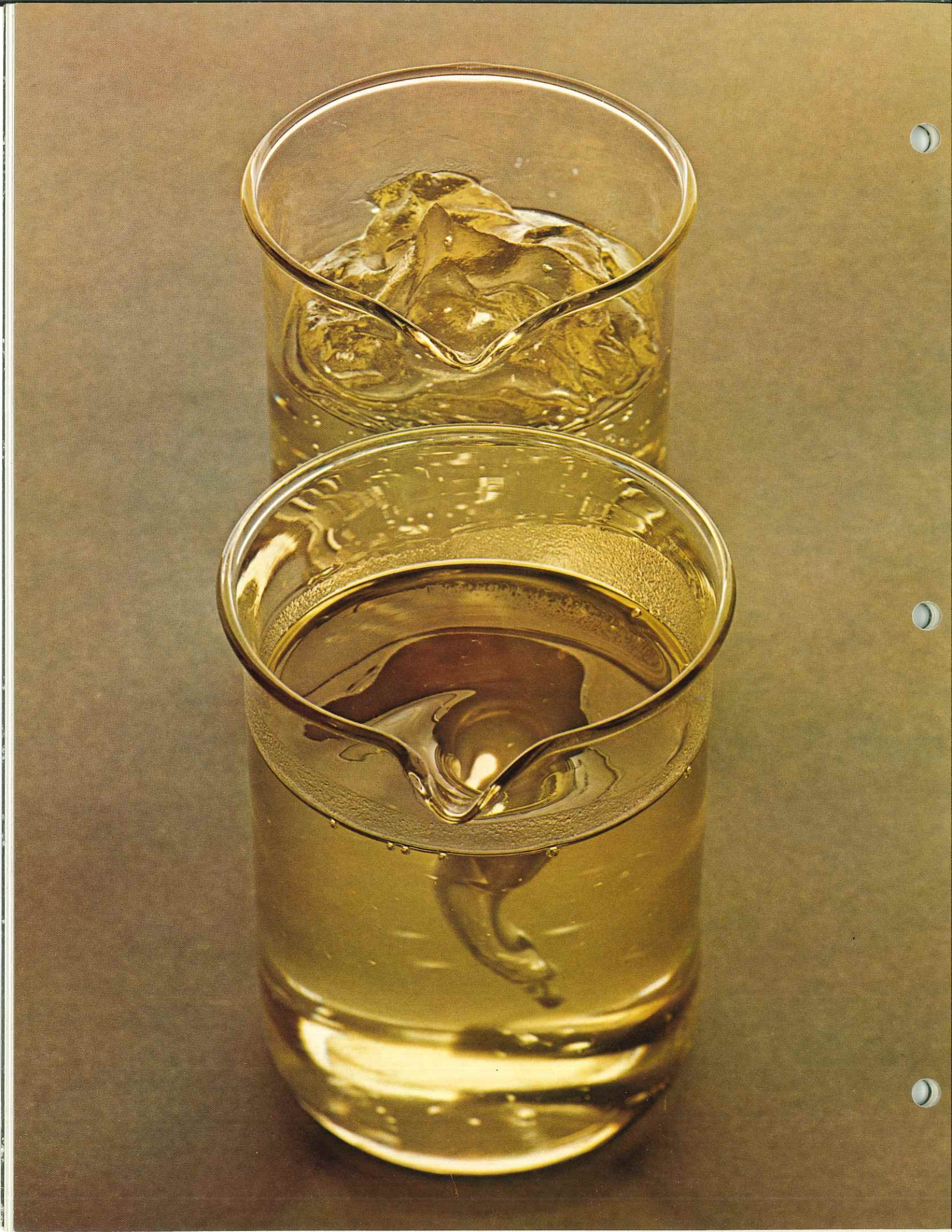


Fig. 19. Cab-O-Sil partially imbedded into a surface increases its coefficient of friction.



Functions

Thickening and Thixotropy

The most important and widespread use of Cab-O-Sil in liquid systems is for the control and increase of viscosity and thixotropy. A thixotropic system is one which exhibits a time-dependent decreasing viscosity or shear stress at a constant shear rate. When the shearing force is eliminated, the viscosity returns over a period of time to its original "at-rest" value. Among compounds which are capable of promoting thixotropy, Cab-O-Sil is frequently the agent of choice because of its extremely high efficiency.

Viscosity increase and thixotropy development are direct results of the Cab-O-Sil network formation through hydrogen bonding, as described under *Mechanisms of Cab-O-Sil,* page 12. The degree of network formation accomplished by Cab-O-Sil in a formulation depends on eight parameters.

These are:

1. the nature of the liquid
2. the concentration of Cab-O-Sil
3. the grade of Cab-O-Sil
4. the degree of dispersion
5. the pH of the system (if aqueous)
6. the temperature of the system
7. the degree of aging of the system
8. the nature of the other minor ingredients of the system, commonly grouped under the general term "additives."

Nature of the system A major determinant of the effect Cab-O-Sil will produce in any system is the nature of the liquid or mixture present in sufficient quantity to be considered the solvent or continuous phase. Network formation is determined to a large degree by the capability of the liquid or matrix to participate in the formation of hydrogen bonds. An introduction to the results of solvent effects on network formation is given in the section on *Mechanisms — Liquid Systems,* page 12.

Commonly used solvents vary over a continuum from highly hydrogen-bonding to non-hydrogen-bonding substances. For purposes of discussion it is necessary to group them into broad classifications. These broad classifications of solvents and systems are presented in Fig. 20. Some of the most commonly used solvents in the various groups are listed in the brochure *Additives for Cab-O-Sil.*

It is in the non-hydrogen-bonding and lower-medium hydrogen-bonding systems that Cab-O-Sil displays its greatest efficiency in network formation, producing the greatest degree of thickening and thixotropy for a given concentration of Cab-O-Sil. When Cab-O-Sil has a greater tendency to hydrogen bond than any other substance present in the system, the hydroxyl groups attached to the silica surface have no competition from other substances in their hydrogen-bonding attraction for each other. Under these conditions, the Cab-O-Sil aggregates orient themselves in the liquid to form hydrogen bonds. The number of bonds formed approaches the maximum number possible for that concentration of Cab-O-Sil, and a high degree of thickening efficiency is exhibited.

Network formation produces an increase in the viscosity of the system whenever it is at rest. When the network is temporarily fragmented during shearing action, the real and apparent viscosities decrease in proportion to increased speed of shear rate or length of time at a constant speed. Upon the cessation of shear force, the viscosity approaches its original value — and again this is achieved efficiently because the Cab-O-Sil has no competition for its own bonding sites. This explains the high degree of thixotropy shown by systems of low hydrogen-bonding ability which are thickened by Cab-O-Sil.

Concentrations of 3% to 6% Cab-O-Sil by weight are usually sufficient to provide gel formation in non-hydrogen-bonding systems. Smaller concentrations will provide any viscosity required up to the stage of gelation.

At the opposite end of the scale, highly hydrogen-bonding systems diminish the capability of Cab-O-Sil aggregates to link with each other. In this type of system there is competition from the liquid molecules for the Cab-O-Sil hydroxyls — so that the statistical probability of Cab-O-Sil-to-Cab-O-Sil bonds is reduced. Instead, chain-termination caused by hydrogen bonding of solvent molecules to the Cab-O-Sil aggregate surfaces will be a significant factor — with larger concentrations of Cab-O-Sil required to produce a given increase in viscosity and thixotropy.

Small amounts of Cab-O-Sil will produce definite increases in viscosity. However, concentrations of 10% or more Cab-O-Sil by weight are required for the formation of gels in systems of high hydrogen-bonding capability.

In systems of intermediate hydrogen-bonding tendency, network formation and solvation will occur at competing rates, determined by the concentration of Cab-O-Sil and the hydrogen-bonding ability of the liquid. The viscosity and thixotropy produced by a given concentration of Cab-O-Sil will depend upon which of these two rates is predominant and the age of the system. Usually, the level required for the desired result must be determined experimentally. Gel formation in systems of this type requires Cab-O-Sil concentrations in the range of 5% to 10% by weight.

Methods for increasing the thickening capability of a given concentration of Cab-O-Sil by using certain substances to modify the nature of a system are described in the section on *Additives,* page 23.

Facing page: Thixotropy. The thixotropy imparted by Cab-O-Sil to a system can cause alternating displays of relatively low viscosity when shear force is applied (front), and higher viscosity when at rest (rear).

I. Highly hydrogen-bonding systems	II. Medium hydrogen-bonding systems II-A. High to medium	II-B. Medium to low	III. Non-hydrogen-bonding systems
Acids	Alcohols (Higher MW)	Alkyds (Oil modified)	Aliphatic hydrocarbons
Alcohols (Lower MW*)	Aldehydes (Higher MW)	Epoxies (some)	Aromatic hydrocarbons
Aldehydes (Lower MW)	Alkyds	Esters (High MW)	Chlorinated solvents
Amides (Lower MW)	Amides (Higher MW)	Ethers (High MW)	Fluorocarbons
Amines (Lower MW)	Amines (Higher MW)	Glycol ether esters	Mineral oils
Carbon disulfide	Epoxies (some)	Polyesters (some)	Terpenes
Esters (Lower MW)	Esters (Medium MW)	Silicones	
Ethers (Lower MW)	Ethers (Medium MW)	Vegetable oils	
Ketones	Glycol ethers	Vinyls	
Nitriles	Polyesters (some)		
Nitro compounds	Polyurethanes		
Peroxides	Thiols (Higher MW)		
Polyols			
Thiols (Lower MW)			
Water			

* *MW = Molecular weight.*

Fig. 20. Classification of common solvents and liquid systems by hydrogen-bonding ability

Concentration of Cab-O-Sil The viscosity and thixotropy produced by Cab-O-Sil shows a continuous smooth-curve plot which increases with increasing concentration of silica. The curvature and slope of these curves are determined by the nature of the system itself.

Some examples of concentration vs. viscosity relationships in various systems are shown in Fig. 21. It should be noted that in preparing graphs of this kind, it is often necessary to place the viscosities on a logarithmic scale. This is because the viscosities often rise very rapidly with small additions of Cab-O-Sil.
When experimental determinations are made to establish the optimum percentage for a given viscosity in a system, small increments of Cab-O-Sil should be added with good dispersion. If the desired viscosity is bypassed in the experiments, the proper concentration can then be obtained from the curve.

Grade of Cab-O-Sil Cab-O-Sil is manufactured in a number of grades to meet a number of special and general product performance requirements. These grades vary with respect to surface area, particle diameter and degree of compression. For any particular application, certain grades are recommended in preference to others.

In general, those grades having larger surface areas will produce higher levels of thickening and thixotropy at a given concentration.

One of the factors governing the selection of the appropriate grade is the dispersibility of the grades and the dispersing equipment available for the incorporation of Cab-O-Sil. Those grades with larger surface areas require more dispersion energy to obtain the greatest benefit from their extra thickening capability. If not properly dispersed, they may exhibit an efficiency that appears to be only equal to that of lower efficiency grades which have been more completely dispersed. The difference in energy required for optimum dispersion is more than compensated for by the increased thickening and thixotropy produced by the high surface area grades.

Compressed grades require some special discussion. While they may have the same surface area as other grades, these have been compressed mechanically. Their bulk density has been increased by a factor of two to three times the original value. Because energy has been expended in effecting this compression, some extra energy is ultimately required to disperse these grades to the same degree as their uncompressed counterparts. This effect, however, is found to be more than compensated for by the abatement in dust, reduced shipping and storage space requirements and fewer bag-handling operations necessary to process equal weights of Cab-O-Sil.

Degree of dispersion In the development of maximum thickening efficiency with Cab-O-Sil, one of the most important factors is the achievement of optimum

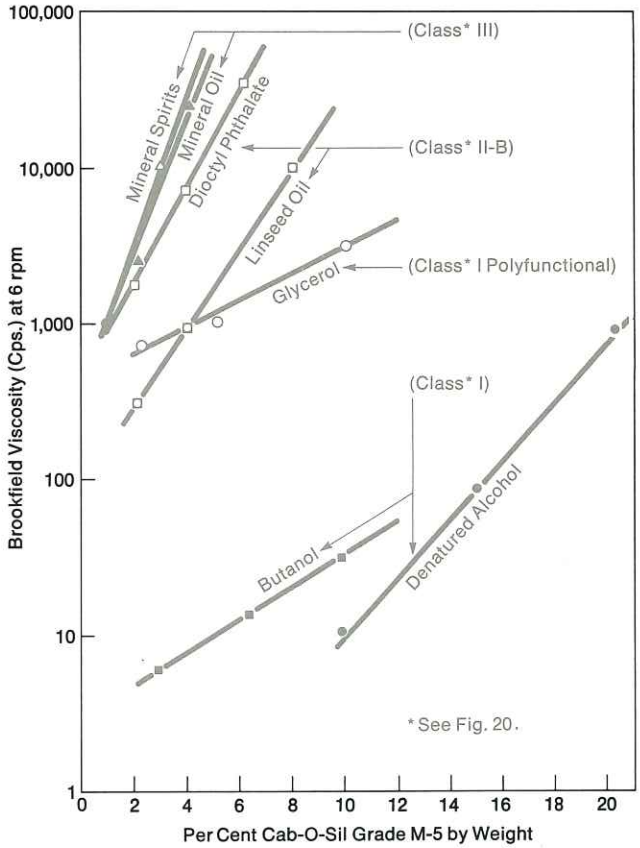


Fig. 21. Effect of Cab-O-Sil on the viscosity of various liquids

dispersion. In non-hydrogen-bonding and slightly hydrogen-bonding systems, the apparent viscosity will increase up to a maximum point with increasing shear rate — or with increasing time at an effective shear rate. This is the stage at which the Cab-O-Sil network has been established to the maximum degree possible, under the conditions of hydrogen-bonding capability of the system and concentration of Cab-O-Sil. In some cases, the optimum shear rate for thickening a given system may be lower than the maximum rate attainable by the equipment.

If shearing force is continued beyond the optimum point, two results are possible, depending on the nature of the system. In some cases the viscosity will merely reach a plateau, after which shear forces from that same piece of equipment will have relatively little effect on it. This is the case with non-hydrogen-bonding liquids. In other cases, however, the apparent viscosity will decrease somewhat. This is caused by the breaking of the Cab-O-Sil network into sections so small that the maximum formation of structure is no longer present (Fig. 22). As such a system ages, the viscosity may or may not increase approaching the maximum value previously achieved. The increase or lack of increase in viscosity depends on the extent to which the network was fragmented and whether or not the Cab-O-Sil and other components of the mixture can act to re-establish the structure (See Fig. 17, page14).

In systems of high hydrogen-bonding capability, dispersion of a given concentration of Cab-O-Sil past the point of maximum viscosity will result in a decrease in viscosity and thixotropy. This is irreversible, and cannot be compensated for by allowing the system to stand at rest. It results from the attachment of hydrogen-bonding substances to the available hydroxyls on the fragments of the Cab-O-Sil network, preventing them from rejoining with each other.

Generalizations on optimum dispersion are difficult to make because of the wide variations encountered from one system to another, depending on the nature of the ingredients. In many cases the optimum stability of viscosity and thixotropy of a system is achieved, however, by carrying out dispersion until the maximum viscosity has been reached — and a plateau effect or a slight downward trend is observed. An equilibrium will then be established when the material is allowed to rest. This would constitute the most efficient network system which can be derived from that particular concentration of Cab-O-Sil, in that particular system and under those dispersing conditions.

The degree of dispersion which will be achieved under a given combination of conditions depends primarily on the shearing capacity of the equipment, the length of shearing time, and the consistency of the mix. Consistency is important, since many pieces of dispersion equipment are designed to operate on fairly viscous mixes, and below a certain viscosity optimum

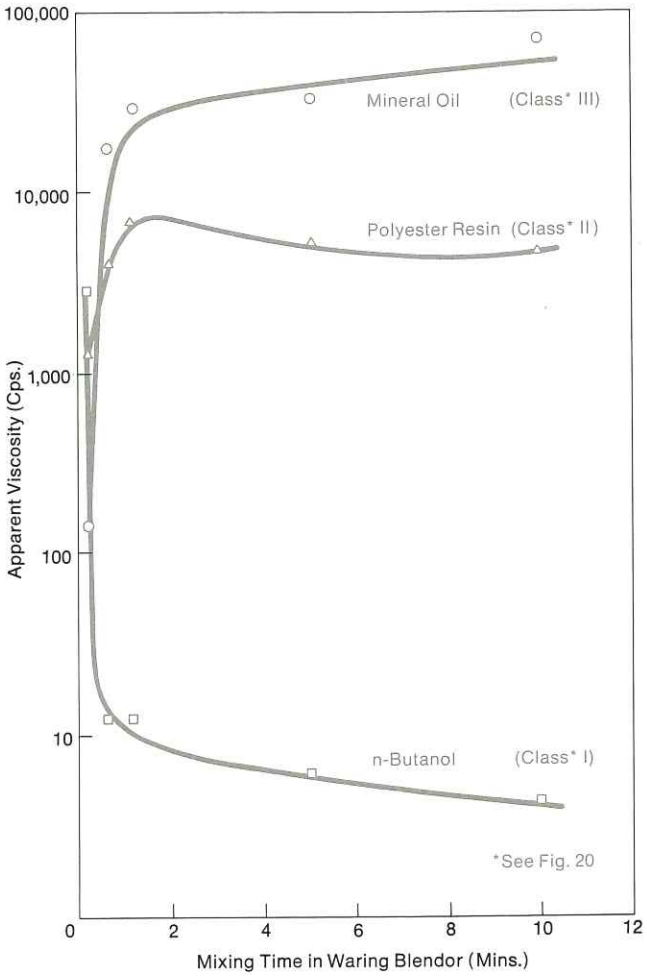
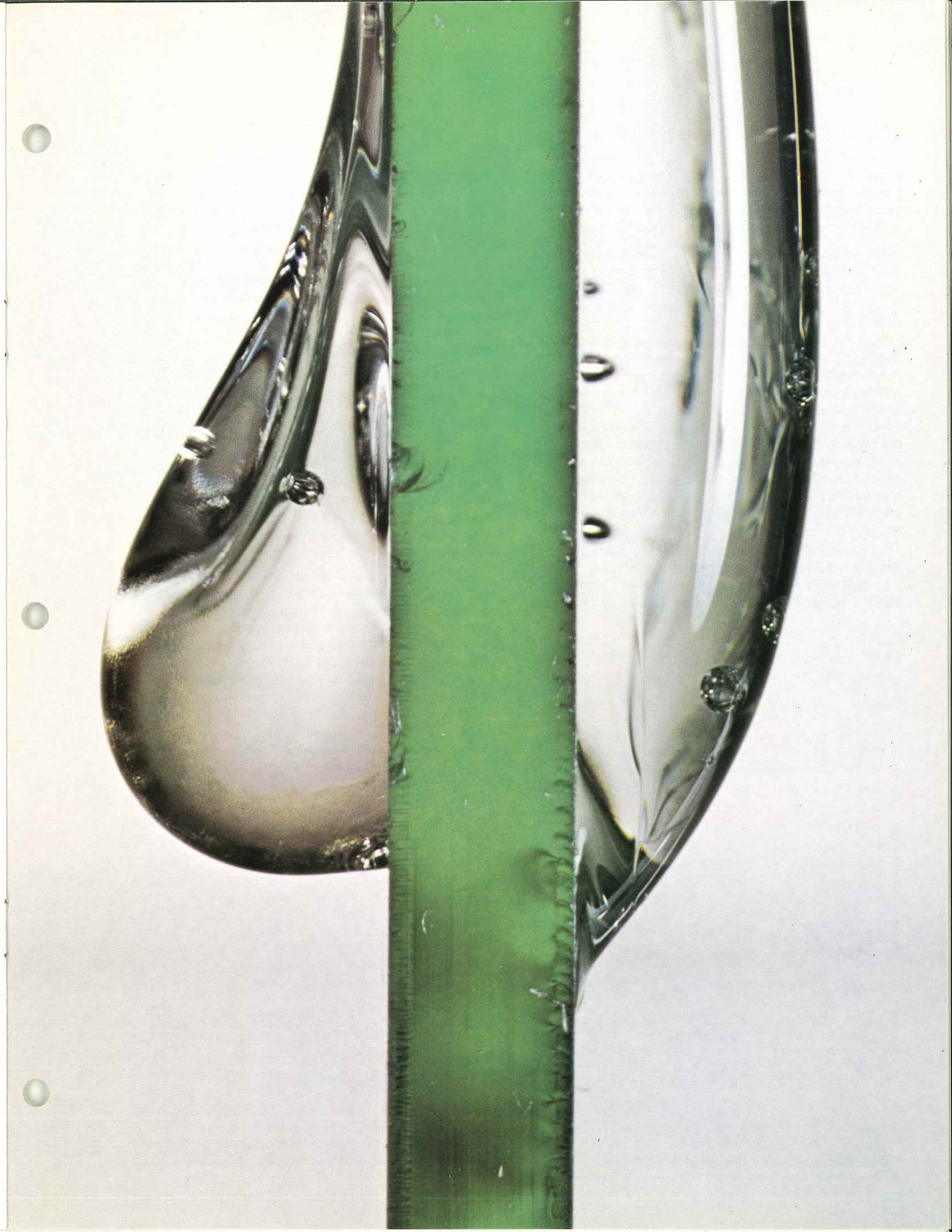


Fig. 22. Effect of mixing time on the viscosity of 2% Cab-O-Sil by weight, Grade M-5, in various liquid systems. RPM approximately 15,000-20,000 depending on load.

Facing page: Anti-Sag. Proper utilization of Cab-O-Sil produces systems which stay in place on sloping or vertical surfaces, as on right — prevents sag and slump, as on left.



shear conditions are not realized. Conversely, other types of equipment work more efficiently at low viscosities. Therefore, the initial and final viscosities must be considered when selecting the method of dispersion.

pH Aqueous systems containing 4% to 18% Cab-O-Sil have a pH slightly on the acidic side, in the range of 3.5 to 4.2, unless other pH modifiers are present. When the pH of an aqueous system containing Cab-O-Sil is changed by acids or bases which do not contribute to network formation, maximum thickening is observed at a pH of about 5.0 to 7.0, depending on the grade and concentration. Cab-O-Sil in aqueous systems normally carries an electronegative charge, which is converted to positive only at very low pH levels. In the range of 4.5 to 5.5, Cab-O-Sil reaches its isolectric point — the pH at which all charges are balanced and the particles become neutral. In this range repulsive forces between similarly-charged particles are completely eliminated, so maximum possibilities for contact — with resulting maximum thickening capability — can occur.

A typical curve for the viscosity vs. pH relationship is shown for pure Cab-O-Sil Grade M-5 in Fig. 23. This 5% dispersion by weight was made by blending with distilled water using a Premier Dispersator[1] at 1,000 rpm for a period of 10 minutes. The pH adjustments were made by titrating with 1.0 *M* NaOH and HC1 solutions, and the viscosity readings were made with a Brookfield LVT viscometer,[2] Spindle #3 at 6 rpm. The pH readings were made with a digital pH meter while stirring slowly with a magnetic stirrer. All of the parameters involved in preparing dispersions, adjusting their pH's and measuring the viscosities are quite critical, so these procedures must be described quite accurately in any discussion of pH effects, and duplicated exactly in order to obtain comparable data.

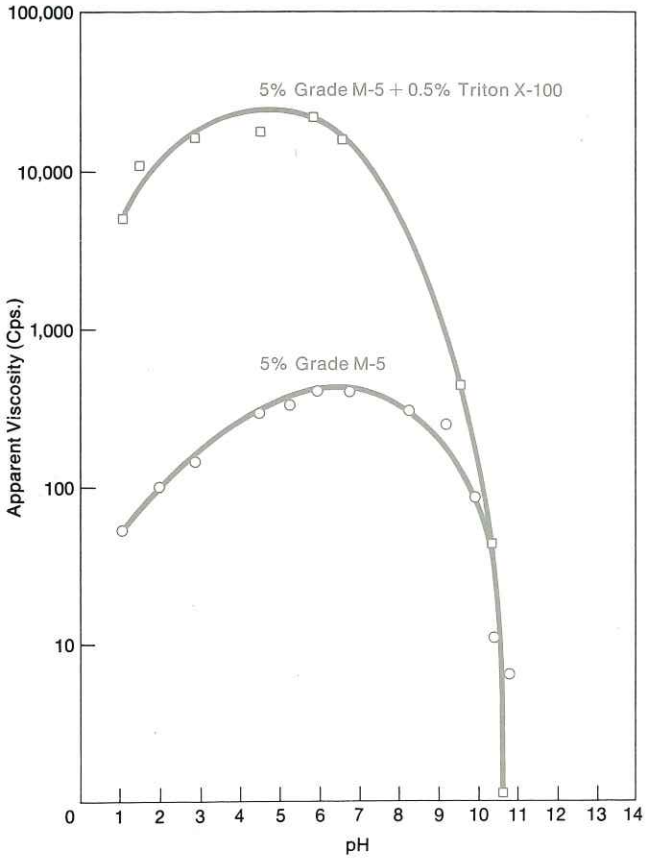


Fig. 23. Effect of pH on the viscosity of aqueous dispersions of Cab-O-Sil.

Acidic sols containing well-dispersed Cab-O-Sil at 5% to 15% by weight show good stability for several days. At levels greater than 15%, however, a sol having a pH of 3.0 to 4.0 will become a thixotropic gel overnight. This gel can be temporarily restored to its original fluidity (sol state) by simple stirring.

Well-dispersed alkaline sols made with alkali metal hydroxides or ammonium hydroxide attain maximum stability at a pH of 8.5 to 10.5. At these pH's the natural negative charge on the Cab-O-Sil particle is increased, and sols containing up to 20% Cab-O-Sil are stable for several months.

Additives such as surfactants and polyfunctional electron donor compounds which contribute to chain formation can be used to increase the thickening efficiency of Cab-O-Sil at a given pH. The effect of an additive, Triton X-100, is shown in the second curve of Fig. 23. For further discussion of the promotion of thickening by additives, see the section on *Additives,* page 23.

[1]*Premier Mill Corp., 224-A Fifth Ave., N.Y., N.Y. 10001.*

[2]*Brookfield Engineering Laboratories, Inc., 240 Cushing St., Stoughton, Mass. 02072.*

Temperature Materials gelled with Cab-O-Sil exhibit remarkable stability of viscosity with respect to temperature. The melting point of Cab-O-Sil itself is approximately 3110°F. (1710°C.). Consequently the aggregates are unaffected within the range of temperatures normally encountered. In most cases, systems thickened with Cab-O-Sil begin to break down only when the other ingredients begin to melt, boil, sublime, oxidize, decompose or otherwise deteriorate.

Viscosity stability curves with respect to temperature are shown in Fig. 24. The stability of viscosity is accompanied by a corresponding stability of thixotropy, since it is the same network formation which produces both properties.

Aging The viscosity and thixotropic stability with respect to aging of products thickened with Cab-O-Sil depend to a large degree upon the other ingredients present. When Cab-O-Sil is the most polar substance included and it has been used in sufficient concentration and properly dispersed, the viscosity, thixotropy and other properties of the mixture may be quite stable for many months or years.

Additives For the purpose of this discussion, additives are defined as substances whose presence in comparatively small amounts can produce a relatively large effect on the modifications in flow characteristics which are imparted to a system by Cab-O-Sil. Frequently additives have been found effective in improving the efficiency of Cab-O-Sil when present in amounts of only 0.1% to 0.5% of the total formulation weight.

Additives are derived from four sources:

1. those put into the system intentionally
2. those present in the components of the formulation as impurities or by-products of their manufacture
3. those introduced with the Cab-O-Sil
4. those absorbed by the system from the environment.

In systems that are not readily responsive to Cab-O-Sil because of their inherent chemical properties, the correct additive can often facilitate efficient viscosity and thixotropic control. In systems where Cab-O-Sil by itself proves efficient, the correct additive can work synergistically with a given amount of Cab-O-Sil to provide even greater viscosity and thixotropy. Alternatively, the additive can be used to reduce the amount of Cab-O-Sil required to produce the desired effects.

In highly hydrogen-bonding liquids the additives that are typically most useful in improving the thickening and thixotropic efficiency of Cab-O-Sil are cationic surfactants. Having polar and non-polar portions in the same molecule, surfactants modify and partially impede the interaction between the Cab-O-Sil surface hydroxyls and the solvent molecules. This allows the Cab-O-Sil network structure to develop more completely, resulting in greater effectiveness in improving viscosity, thixotropy and suspending properties.

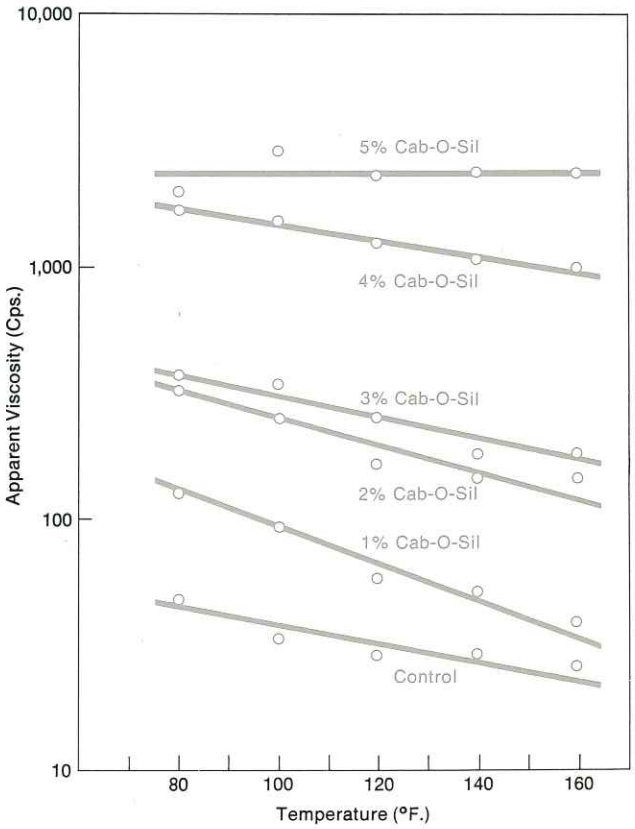


Fig. 24. Stabilization of viscosity of paraffin oil with respect to temperature by the addition of Cab-O-Sil, Grade M-5.

In non-hydrogen-bonding liquids the additives which prove most useful are short chain molecules with more than one functional group capable of hydrogen bonding, such as glycols. These act as bridging compounds between some of the surface hydroxyls of adjacent Cab-O-Sil aggregates, forming chains consisting of alternating silica aggregates and organic molecules (Fig. 25).

Bridging compounds are often added to moderately or non-hydrogen-bonding Cab-O-Sil formulations to bring about improved network formation. Levels equal to 15% to 25% of the weight of Cab-O-Sil in the formula can result in great benefits in physical properties and considerable improvements in cost-efficiency. However, at higher concentrations these same compounds can solvate a large proportion of the available Cab-O-Sil surface hydroxyls, thereby acting to inhibit chain formation instead of promoting it.

The hydrogen-bonding capability of a system can be roughly determined by referring to Fig. 20. The recommended classifications of additives appear as dots in the appropriate boxes in Fig. 26, arranged by classification of the system. Specific additive compounds, identified by proprietary name, manufacturer and HLB (where applicable) are presented in Fig. 27.

Recommendations for additives which have been found to be widely useful in particular industries and commercial applications are presented in the brochure, *Additives for Cab-O-Sil.* The same brochure details specific laboratory instructions for selecting effective additives for use in systems of known hydrogen-bonding capability. It also explains how to determine the hydrogen-bonding classifications for complex Cab-O-Sil-containing systems. Such information is sometimes unavailable through other sources, or obtainable only with difficulty.

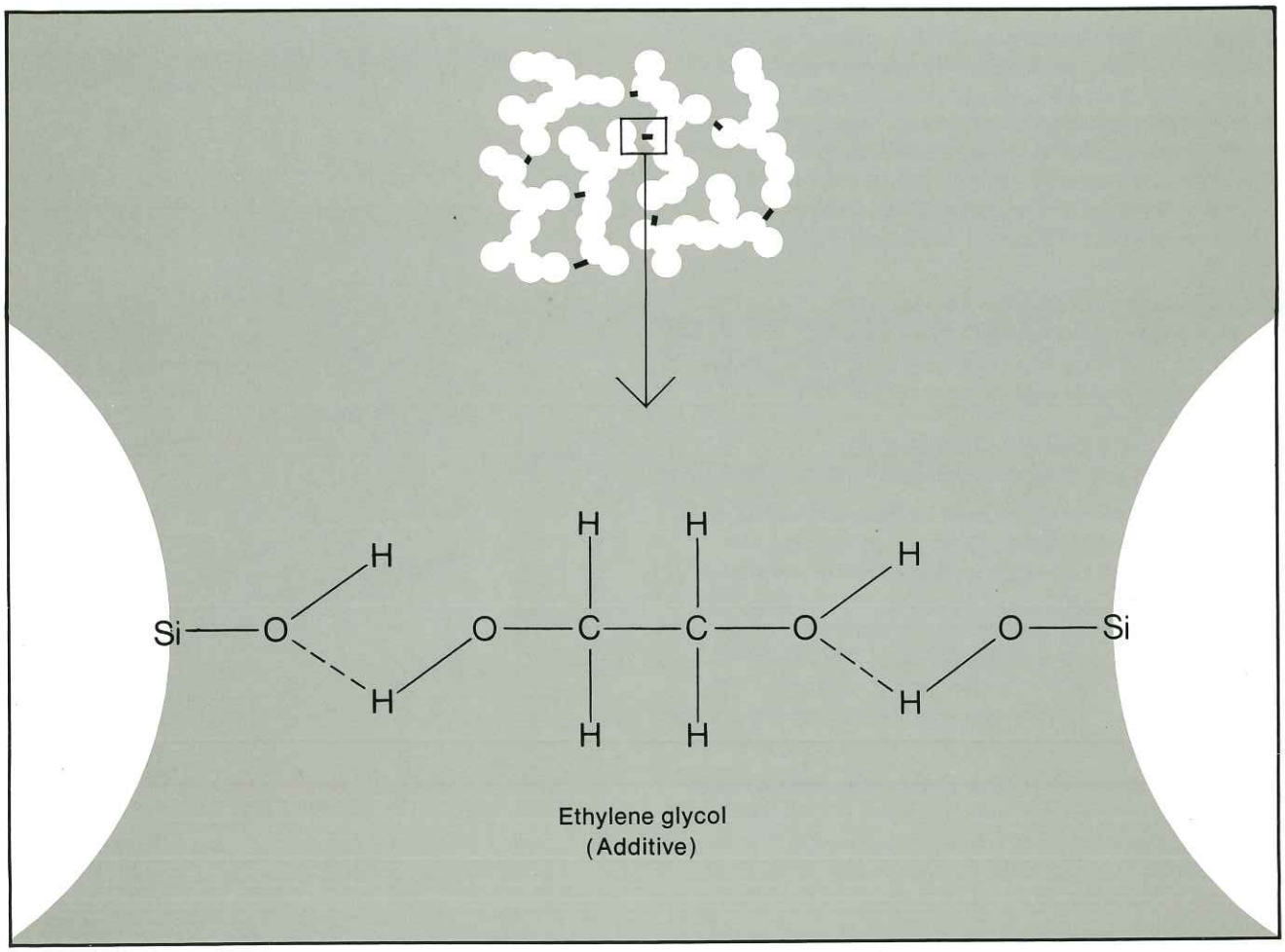


Fig. 25. Chemical compounds having short chain polyfunctional molecules can hydrogen bond with two or more Cab-O-Sil aggregates, thus promoting and extending network formation.

	I.[1] Highly hydrogen-bonding systems	II. Medium hydrogen-bonding systems II-A. High to medium	II-B. Medium to low	III. Non-hydrogen-bonding systems
Surfactants				
Cationic	●	●		
Anionic			●	●
Nonionic				
low HLB[2] (1-6)		●		
medium HLB (7-12)	●	●	●	
high HLB (13-20)	●	●	●	
Other additives				
Polyfunctional				
short chain (less than 5 carbon atoms)		●	●	●
long chain	●	●	●	
Alkali	●	●	●	●

This table is only a guide. The recommendations for highly polar and non-polar solvents are quite reliable. However, a system may shift between the middle classifications with only a slight increase or decrease in the number of hydrogen-bonding sites.

[1] *For classes of solvents, see Fig. 20.*

[2] *HLB: hydrophilic-lipophilic balance. See Fig. 27. For a further discussion of HLB values see* McCutcheon's Detergents and Emulsifiers, 1971 Annual, *Allured Pub. Co., p. 223.*

Fig. 26. Classes of additives recommended for systems classified by their degree of hydrogen bonding.

Surfactant additives

Trade name	Chemical name or class	State	Conc.	Maker[1]	HLB[2]
Cationic					
ADOGEN 572	Oleyl trimethylene diamine	liquid	100%	ASH	
ARQUAD C-50	N-alkyl trimethyl ammonium chloride	liquid	50%	A	15.0
ARQUAD 2HT-75	Distearyl dimethyl ammonium chloride	paste	75%	A	
ARQUAD 2S-75	Disoya dimethyl ammonium chloride	liquid	75%	A	
DUOMAC T	N-tallow trimethylene diamine diacetate	solid	85%	A	
DUOMEEN TDO	N-tallow trimethylene diamine dioleate	solid	100%	A	
ETHOMEEN 18/60	Tertiary amine; ethylene oxide condensate of stearylamine	solid	100%	A	
ETHOQUAD 18/12	Polyethoxylated quaternary ammonium chloride	liquid	75%	A	
Anionic					
AEROSOL MA	Dihexyl sodium sulfosuccinate	liquid	80%	AM	
ALROWET D-65	Dioctyl sodium sulfosuccinate	liquid	65%	CG	
DAXAD 30	Sodium salt of a polymerized carboxylic acid	liquid	25%	G	
NEKAL BA-75	Sodium alkylnaphthalene sulfonate	powder	53%	GAF	
TAMOL 731	Sodium salt of polymeric carboxylic acid	powder or solution	25%	R&H	
ULTRAWET 35KX	Sodium linear alkylate sulfonate	liquid	33.5%	AR	
	Cobalt naphthenate	solution	6%	T	
	Cobalt octoate	solution	12%	T	
	Sodium oleate	solid	100%	WI	
	Sodium stearate	solid	100%	WI	
	Sulfated castor oil (Turkey Red Oil)	liquid	100%	N	
	Zinc hydroxy stearate	solid	100%	WI	
Nonionic					
ADVAWET 33	Polygylcol ester	liquid	100%	C	
IGEPAL CO SERIES	Nonylphenoxypoly (ethyleneoxy) ethanols	solids and liquids	100%	GAF	4.6 to 15.2
PLURONIC F, P and L SERIES	Derivatives of ethylene oxide, propylene oxide, propylene glycol	solids, pastes and liquids	100%	W	1 to 30.5
SPAN SERIES	Sorbitan esters	solids and liquids	100%	ICI	1.8 to 8.6
SURFONIC N SERIES	Nonylphenoxy polyethoxy ethanols	solids and liquids	100%	J	Approx. 2 to 13+
TERGITOL NP SERIES	Nonylphenyl polyethylene glycol ethers	solids and liquids	100%	UC	8.9 to 17.8
TRITON X SERIES	Octylphenoxy polyethoxy ethanols	liquids	70% to 100%	R&H	3.6 to 17.9
TWEEN SERIES	Polyoxyethylene sorbitan esters	solids and liquids	100%	ICI	9.6 to 16.7

Fig. 27. Additives listed by classification

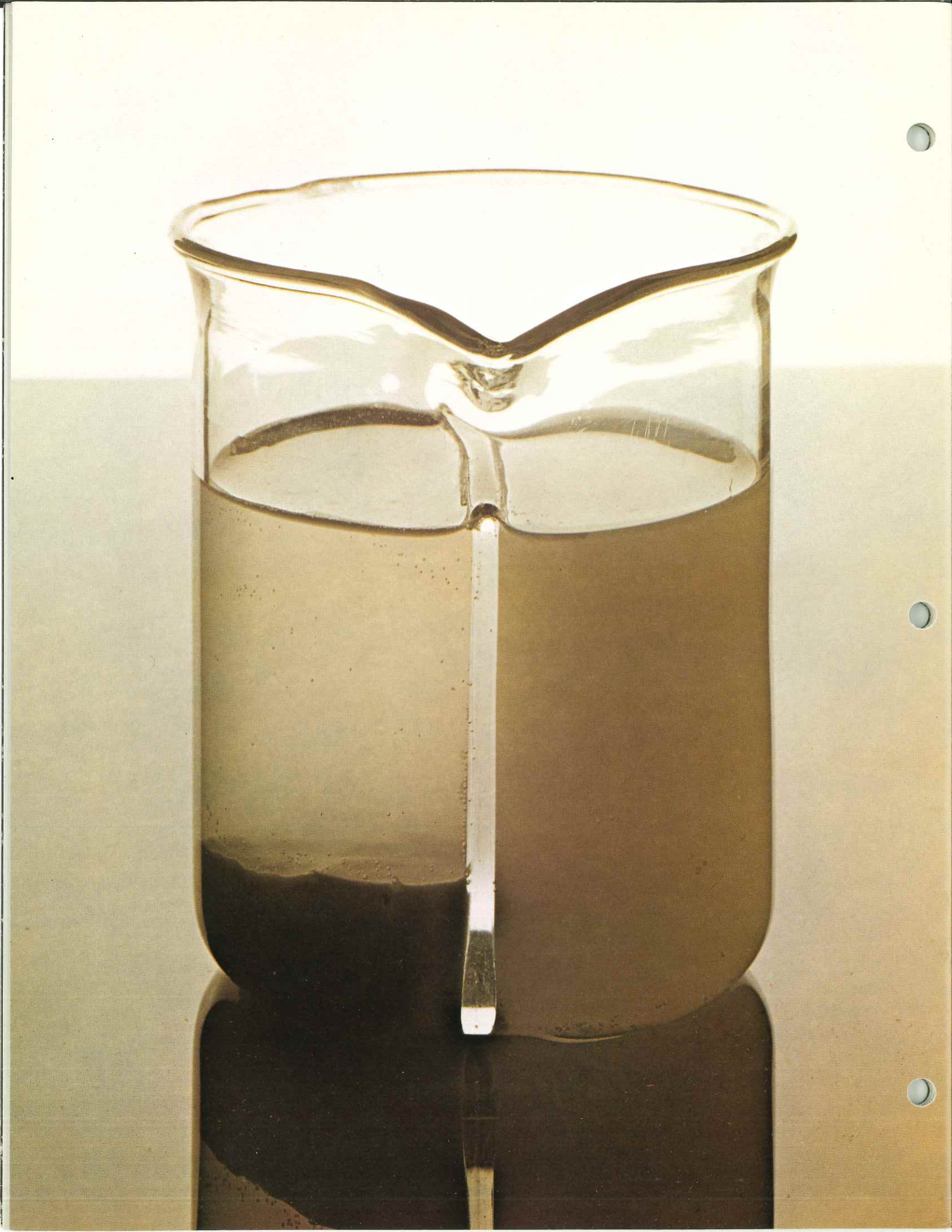
Other additives

Trade name	Chemical name or class	State	Conc.	Maker[1]	HLB[2]
Polyfunctional					
short chain					
	Ethylene diamine	liquid	100%		
	Ethylene glycol	liquid	100%		
	Glycerine	liquid	100%		
	Propylene glycol	liquid	100%		
long chain					
ATLAS G-2240	Polyoxyethylene (6) sorbitol	liquid	100%	ICI	
CARBOWAX SERIES	Polyethylene glycols and their methyl ethers	solids and liquids	100%	UC	
UCON SERIES	Polyalkylene glycols	liquids	100%	UC	
Alkali					
	Aqueous KOH, NaOH, etc.	solution			
	KOH in alcohol	solution			
	(Pure water or alcohols can be used as additives in systems of low polarity)				

[1]*Manufacturers:*

A = Armak Chemicals Div./Akzona, Inc.
AM = American Cyanamid Co., Industrial Chemicals and Plastics Div.
AR = ARCO Chemical Co.
ASH = Ashland Chemical Co.
B = Baker Castor Oil Co.
C = Cincinnati Milacron Chemicals, Inc.
CG = Ciba-Geigy
G = W. R. Grace and Co., Polymers and Chemicals Div.
GAF = GAF Corp., Chemical Div.
ICI = I.C.I. America, Inc.
J = Jefferson Chemical Co.
N = Nopco Chemical Division, Diamond Shamrock Chemical Co.
R&H = Rohm and Haas Co.
T = Tenneco Chemicals, Inc.
UC = Union Carbide Corp., Chemicals and Plastics Div.
W = Wyandotte Chemical Div., BASF Corp.
WI = Witco Chemical Corp., Organics Div.

[2]*See Footnote 2, Fig. 26.*



Suspension

Cab-O-Sil is used as a suspending or anti-settling agent in many different types of applications. These can be for the suspension of solids in liquids or for suspension of liquids in liquids (emulsions). In some cases the desired result is the maintenance of true and complete suspensions over long periods of time. In other types of products the purpose is to eliminate hard settling so that the material is readily re-dispersed when the mixture is shaken or stirred before use.

The suspending ability of Cab-O-Sil is produced by its formation of a network when it is dispersed in a liquid. The network serves to keep droplets or particles of other suspended materials separated from each other so that they cannot readily coalesce and undergo phase separation. The increased viscosity of the system resulting from the use of Cab-O-Sil also helps to impede the rate of movement of all the ingredients in the mixture. (See Fig. 28.)

Particulate suspension In aerosol products, Cab-O-Sil helps to maintain the intimate mixture among active ingredients, solvents and propellants. Solid ingredients included in aerosols are prevented from settling into a hard cake which can later clog the dip tube or nozzle of the container. Many aerosol packagers have found that the use of Cab-O-Sil to promote re-dispersion when the cans are shaken prior to use eliminates the need for the ball which was formerly put into the can to break up sediments. In some cases, the incorporation of Cab-O-Sil has made possible the aerosol packaging of hygroscopic, gummy solids such as aluminum chlorhydrate and aluminum chloride hexahydrate, which could not otherwise be produced as aerosols. Cab-O-Sil levels from 0.5% to 2.0% by weight are usually sufficient to promote suspension and eliminate hard settling.

Emulsification Cab-O-Sil performs well as a stabilizer for oil-in-water emulsions. Stable emulsions ranging from 25% oil to 75% oil have been prepared. As the concentration of polar compounds goes up, the amount of Cab-O-Sil required increases. This is a result of the competition for Cab-O-Sil bonding sites by the polar ingredients. Cab-O-Sil requirements usually fall in the range of 1% to 5% by weight of the total emulsion formula.

The action of Cab-O-Sil is largely unaffected by the order of addition of ingredients. In many cases, equally good results are obtained by adding the Cab-O-Sil to the oil phase or to the aqueous phase. The resulting Cab-O-Sil dispersion can then be added to the other phase or vice versa. However, if the formulation contains ingredients which change the pH or buffer it, the order of addition of these pH-modifying ingredients may be very critical. In these cases it is necessary to determine experimentally the best order for emulsification and stability, and then adhere to it rigorously in production.

The use of sufficient Cab-O-Sil to produce good suspension stability will result in some viscosity increase in the product. While ordinary thickening may not be considered desirable in some cases, the effect of Cab-O-Sil is usually acceptable because of its unusual thixotropic nature. The thixotropy of the Cab-O-Sil-stabilized liquid will be so great that the shearing force of shaking and pouring will make the product behave as a mixture of much lower apparent viscosity would be expected to act.

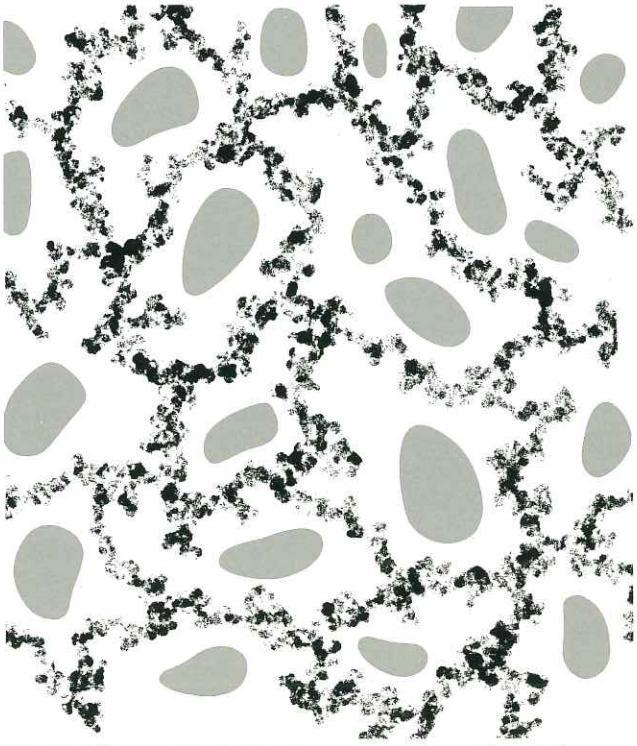


Fig. 28. Diagram illustrating the suspending action of the Cab-O-Sil network. Particles of pigment or other undissolved solids are suspended in the network and prevented from coalescing with each other, which would produce phase separation.

Facing page: Suspension. Suspended Cab-O-Sil holds other particulate matter in suspension, as on right — prevents settling, as on left.

Free flow and anti-caking

The sub-microscopic size and enormous surface area of Cab-O-Sil enable it to function as a spacing agent between the relatively large particles of most powdered materials. Cab-O-Sil acts as a dry lubricant, promoting free flow of the powder and preventing caking and lumping. The Cab-O-Sil layer decreases bulk tensile strength and shear strength, while neutralizing the electrostatic charge on the particles. The moisture adsorbing ability of Cab-O-Sil also helps it to perform its anti-caking function. Even powders which have already become caked can usually be rendered free flowing by blending in 2% Cab-O-Sil by weight, or less.

Solid systems Most powdered materials can be kept free flowing by a 1% concentration of Cab-O-Sil. This is true of such differing materials as sulfur, table salt, sodium bicarbonate and instant food mixes. When testing Cab-O-Sil in new applications, the 0.5% level is a good starting point for the first experiment. The optimum concentration can then be determined by working up or down in small steps.

Products which cannot be processed beyond a sticky or tacky powder can be made free flowing by adding the proper level of Cab-O-Sil as a final finishing step. Cab-O-Sil can also be used to promote free flow in spray-dried or freeze-dried products. In some cases it can be introduced into the original emulsion, suspension or solution, or blended in later. Cab-O-Sil has also been used to coat powdered and pelletized products which must be sterilized, to prevent them from caking during or after autoclaving.

Dry carrier for liquids Cab-O-Sil can convert many liquids into free-flowing powders for ease of handling and blending into dry formulations. The levels of Cab-O-Sil required for this function cover a wide range, depending on the polarity and hydrogen-bonding ability of the liquids involved. Effective concentrations are usually from 10% to 40% by weight.

Fluidized beds Cab-O-Sil's usefulness in the fluidized bed operations which are now used in many industries is produced by a combination of water-scavenging and physical spacing. Even beds which are allowed to lie dormant for weeks at a time are easily activated and uniformly fluidized when Cab-O-Sil is present in amounts of 0.25% to 1.0% by weight. This subject is given a more complete treatment in the Cabot brochure titled *Cab-O-Sil in Coatings.*

Reinforcement

Cab-O-Sil has the ability to reinforce or increase the cohesive strength of a solid system. It is believed that this property stems from the formation of a network structure. The use of Cab-O-Sil as a reinforcing agent is common in adhesives, sealants, rubber and other elastomeric products.

Cab-O-Sil has been called the "white carbon black." In many cases the reinforcing effects produced by Cab-O-Sil are similar to those of carbon black. The white color of Cab-O-Sil extends its usefulness into the range of white and tinted products in which carbon black cannot be used.

For reinforcement of rubbers and other elastomers, Cab-O-Sil is used at levels from 2.5% to 25.0%. Wide variations in the amount used occur because of inherent variables in the materials involved and differences in the properties desired in the final products. In adhesives and sealants, usages range from 1% to 10% by weight. In most cases, 2% to 5% additions are found to give very satisfactory increases in cohesive strength. This subject is discussed more fully in the brochure *Cab-O-Sil in Adhesives.*

Gloss reduction

Cab-O-Sil is used to produce a reduction in the glossiness of materials used for protective or decorative coatings. Manufacturers of shellacs, lacquers, varnishes and other coatings take advantage of this effect, which is produced by the light-scattering ability of the tiny agglomerates of Cab-O-Sil. The reduced sheen results in the "hand-rubbed" appearance which is very desirable in many applications such as furniture, woodwork and other finished products.

When used for gloss reduction, Cab-O-Sil gives optimum results when ground to a Hegman Fineness of 5 to 6. A discussion of proper grinding and dispersing techniques, and typical levels of optimum concentration for various effects and types of coatings, will be found in the brochure titled *Cab-O-Sil in Coatings.*

Anti-slip

The incorporation of Cab-O-Sil in material surfaces or surface coatings adds a certain frictional resistance to slippage. This property is imparted by the microroughness of the Cab-O-Sil aggregates embedded in the surface. Adhesive and protective coatings of various types, as well as treated cartons and packaging materials, benefit from this function of Cab-O-Sil. Concentrations of 1% to 3% by weight are used for this purpose.

Anti-blocking

Many items tend to adhere to each other when stored in close contact over periods of time. This is true of some plastics, many rubber items, and certain types of coatings such as hot-melt adhesives. Sometimes a stack of individual items is converted by storage into a single unit which cannot be divided again into its component parts without the expenditure of time and energy. This problem, known as blocking, is particularly troublesome when the storage area is hot and/or humid.

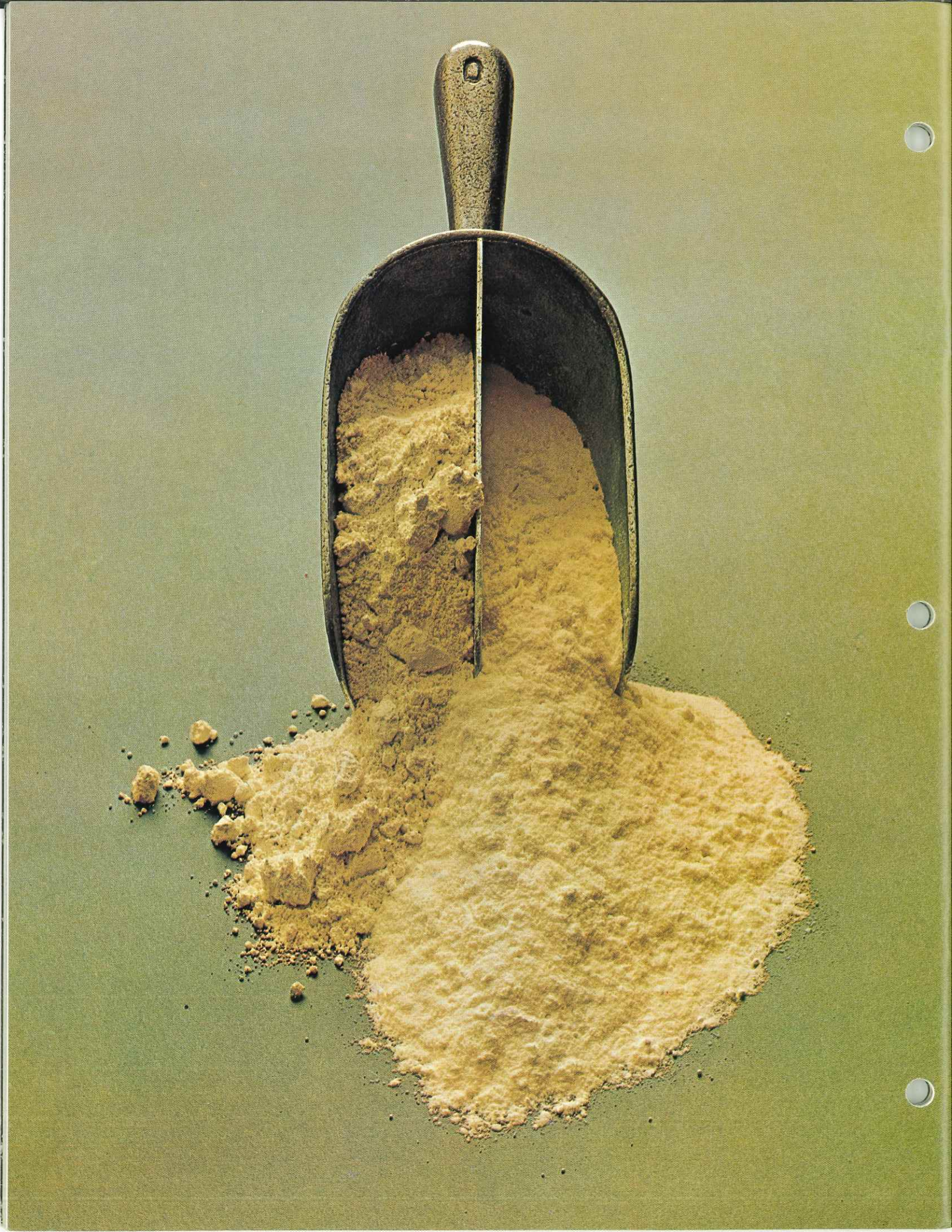
Cab-O-Sil, by imparting a small but effective roughness to the surface of any film in which it is imbedded, prevents complete contact between the film and any other surface. The resulting discontinuities in contact between the two surfaces help to lessen the tendency of the surfaces to adhere to each other. This non-uniformity of contact is increased when both of the contiguous surfaces are coated with Cab-O-Sil. If the coating is an adhesive in dry form, activation by wetting or melting will submerge the Cab-O-Sil particles in the film and perfect contact between surfaces is made possible.

Insulation

Cab-O-Sil, like all other forms of silica, is a poor conductor of heat and electricity. It has excellent temperature stability, previously discussed in the section on *Temperature,* page 23. Insulating properties with respect to electricity, heat and cryogenics are produced or enhanced in chemical systems by the addition of Cab-O-Sil. For example, both the dielectric constant and the dielectric loss factor of PVC insulation are reduced substantially by the use of 3% by weight.

	Thickening	Thixotropy	Anti-sag	Hold-out	Thermal Viscosity Stabilization	Suspension	Emulsification	Reinforcement	Gloss Reduction	Insulation	Free Flow	Anti-caking	Fluidization	Carrier for Liquids	Anti-slip	Anti-blocking
Adhesives	●	●	●		●	●	●	●			●	●			●	●
Aerosols		●	●			●	●		●			●				
Animal Feeds											●	●				●
Chemical Specialties	●	●	●		●	●	●				●	●		●		
Chemicals — Industrial	●	●				●	●				●	●	●	●		
Coatings — Liquid	●	●	●	●	●	●	●	●	●							
Coatings — Powder	●	●						●			●	●	●			
Cosmetics	●	●			●	●	●				●	●		●		
Elastomers	●	●				●		●								
Fertilizers											●	●				
Foods											●	●		●		
Inks	●	●	●	●	●	●	●									
Insecticides	●	●				●	●				●	●		●		
Insulation — Electrical	●	●				●		●		●						●
Insulation — Thermal	●	●				●		●		●						●
Lubricants	●	●	●		●	●										
Pharmaceuticals	●	●			●	●	●				●	●	●	●		
Plastisols	●	●	●			●										
Polishes	●	●				●	●									
Reproduction Papers				●					●							
Resins — Liquid	●	●	●	●	●				●							
Resins — Powder											●	●	●			
Rubbers	●	●				●		●								
Sealants	●	●	●		●	●		●								
Silicones	●	●	●		●	●		●								
Waxes	●	●	●			●	●		●							

Cab-O-Sil performs 16 functions in many product groups



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Facing page: Free flow. Addition of a small amount of Cab-O-Sil converts the lumpy, caking material on left to the free-flowing powder on right.

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